

11-01-00

A

UTILITY PATENT APPLICATION TRANSMITTAL
(Small Entity)*(Only for new nonprovisional applications under 37 CFR 1.53(b))*Docket No.
14917.1.4Total Pages in this Submission
109**TO THE ASSISTANT COMMISSIONER FOR PATENTS****Box Patent Application**
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

INTEGRATED MONOLITHIC MICROFABRICATED ELECTROSPRAY AND LIQUID CHROMATOGRAPHY SYSTEM AND METHOD

and invented by:

James E. Moon, Gary A. Schultz, Thomas N. Corso, Timothy J. Davis, Gregory J. Galvin, and Stephen LowesIf a **CONTINUATION APPLICATION**, check appropriate box and supply the requisite information:☐ Continuation ☒ Divisional ☐ Continuation-in-part (CIP) of prior application No.: 09/156,507

Which is a:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: _____

Which is a:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: _____

Enclosed are:

Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 62 pages and including the following:
 - a. ☒ Descriptive Title of the Invention
 - b. ☒ Cross References to Related Applications *(if applicable)*
 - c. ☐ Statement Regarding Federally-sponsored Research/Development *(if applicable)*
 - d. ☐ Reference to Microfiche Appendix *(if applicable)*
 - e. ☒ Background of the Invention
 - f. ☒ Brief Summary of the Invention
 - g. ☒ Brief Description of the Drawings *(if drawings filed)*
 - h. ☒ Detailed Description
 - i. ☒ Claim(s) as Classified Below
 - j. ☒ Abstract of the Disclosure

**UTILITY PATENT APPLICATION TRANSMITTAL
(Small Entity)**

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.

14917.1.4

Total Pages in this Submission

109

Application Elements (Continued)

3. ☒ Drawing(s) *(when necessary as prescribed by 35 USC 113)*
a. ☐ Formal b. ☒ Informal Number of Sheets 26
4. ☒ Oath or Declaration
a. ☐ Newly executed *(original or copy)* ☐ Unexecuted
b. ☒ Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional application only)*
c. ☒ With Power of Attorney ☐ Without Power of Attorney
d. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application,
see 37 C.F.R. 1.63(d)(2) and 1.33(b).
5. ☒ Incorporation By Reference *(usable if Box 4b is checked)*
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under
Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby
incorporated by reference therein.
6. ☐ Computer Program in Microfiche
7. ☐ Genetic Sequence Submission *(if applicable, all must be included)*
a. ☐ Paper Copy
b. ☐ Computer Readable Copy
c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

Accompanying Application Parts

8. ☐ Assignment Papers *(cover sheet & documents)*
9. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)*
10. ☐ English Translation Document *(if applicable)*
11. ☐ Information Disclosure Statement/PTO-1449 ☐ Copies of IDS Citations
12. ☒ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☒ Certificate of Mailing
☐ First Class ☒ Express Mail *(Specify Label No.):* EL675131575US

**UTILITY PATENT APPLICATION TRANSMITTAL
(Small Entity)**

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
14917.1.4

Total Pages in this Submission
109

Accompanying Application Parts (Continued)

15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☒ Small Entity Statement(s) - Specify Number of Statements Submitted: 2
17. ☒ Additional Enclosures *(please identify below)*:

Associate Power of Attorney
Assignment Documents (2 sets - 8 pages and 6 pages)
Credit Card Payment Form Authorizing \$355.00

Request That Application Not Be Published Pursuant To 35 U.S.C. 122(b)(2)

18. ☐ Pursuant to 35 U.S.C. 122(b)(2), Applicant hereby requests that this patent application not be published pursuant to 35 U.S.C. 122(b)(1). Applicant hereby certifies that the invention disclosed in this application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication of applications 18 months after filing of the application.

Warning

An applicant who makes a request not to publish, but who subsequently files in a foreign country or under a multilateral international agreement specified in 35 U.S.C. 122(b)(2)(B)(i), must notify the Director of such filing not later than 45 days after the date of the filing of such foreign or international application. A failure of the applicant to provide such notice within the prescribed period shall result in the application being regarded as abandoned, unless it is shown to the satisfaction of the Director that the delay in submitting the notice was unintentional.

UTILITY PATENT APPLICATION TRANSMITTAL
(Small Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
14917.1.4

Total Pages in this Submission
103

Fee Calculation and Transmittal

CLAIMS AS FILED

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	1	- 20 =	0	x \$9.00	\$0.00
Indep. Claims	1	- 3 =	0	x \$40.00	\$0.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0.00
BASIC FEE					\$355.00
OTHER FEE (specify purpose) _____					\$0.00
TOTAL FILING FEE					\$355.00

- ☐ A check in the amount of _____ to cover the filing fee is enclosed.
- ☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. 23-3178 as described below. A duplicate copy of this sheet is enclosed.
- ☐ Charge the amount of \$355.00 as filing fee.
- ☒ Credit any overpayment.
- ☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.
- ☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).

Dated: October 31, 2000


Signature

David O. Seeley
Attorney for Applicants
Registration No. 30,148



022913

DOS:cm
CC:

PATENT TRADEMARK OFFICE

SMALL BUSINESS
Docket No.: 200701/1030

Applicant or Patentee : James E. Moon, Gary A. Schultz, Thomas N. Corso,
Timothy J. Davis, Gregory J. Galvin, Stephen Lowes
Serial or Patent No. : 09/156,507
Filed or Issued : September 17, 1998
For : INTEGRATED MONOLITHIC MICROFABRICATED
ELECTROSPRAY AND LIQUID CHROMATOGRAPHY
SYSTEM AND METHOD

**VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) and 1.27(c)) - SMALL BUSINESS CONCERN**

I hereby declare that I am

- ☐ the owner of the small business concern identified below:
☒ an official of the small business concern empowered to act on behalf of the concern
identified below:

NAME OF CONCERN : Kionix, Inc.
ADDRESS OF CONCERN : 22 Thornwood Drive
Ithaca, New York 14850

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled **INTEGRATED MONOLITHIC MICROFABRICATED ELECTROSPRAY AND LIQUID CHROMATOGRAPHY SYSTEM AND METHOD** by inventors James E. Moon, Gary A. Schultz, Thomas N. Corso, Timothy J. Davis, Gregory J. Galvin, Stephen Lowes described in

- ☐ the specification filed herewith
☒ U.S. Patent Application Serial No.: 09/156,507
Filed: September 17, 1998
☐ U.S. Patent No.:
Issued:

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e). *NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27).

NAME : Advanced Bioanalytical Services, Inc.
ADDRESS : 15 Catherwood Road, Ithaca, New York 14850

☐ INDIVIDUAL ☒ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

09/156,507-1030

NAME :
ADDRESS :

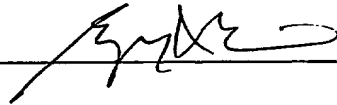
☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING : Gregory J. Galvin
TITLE OF PERSON OTHER THAN OWNER : President
ADDRESS OF PERSON SIGNING : 22 Thornwood Drive
Ithaca, New York 14850

SIGNATURE: _____



DATE: 3/11/95

007001 43620460

Applicant or Patentee : James E. Moon, Gary A. Schultz, Thomas N. Corso,
Timothy J. Davis, Gregory J. Galvin, Stephen Lowes
Serial or Patent No. : 09/156,507
Filed or Issued : September 17, 1998
For : INTEGRATED MONOLITHIC MICROFABRICATED
ELECTROSPRAY AND LIQUID CHROMATOGRAPHY
SYSTEM AND METHOD

**VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) and 1.27(c)) - SMALL BUSINESS CONCERN**

I hereby declare that I am

- ☐ the owner of the small business concern identified below:
☒ an official of the small business concern empowered to act on behalf of the concern
identified below:

NAME OF CONCERN : Advanced Bioanalytical Services, Inc.
ADDRESS OF CONCERN : 15 Catherwood Road
Ithaca, New York 14850

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled
**INTEGRATED MONOLITHIC MICROFABRICATED ELECTROSPRAY AND LIQUID
CHROMATOGRAPHY SYSTEM AND METHOD** by inventors James E. Moon, Gary A.
Schultz, Thomas N. Corso, Timothy J. Davis, Gregory J. Galvin, Stephen Lowes described in

- ☐ the specification filed herewith
☒ U.S. Patent Application Serial No.: 09/156,507
Filed: September 17, 1998
☐ U.S. Patent No.:
Issued:

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e). *NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27).

NAME : Kionix, Inc.
ADDRESS : 22 Thornwood Drive, Ithaca, New York 14850

☐ INDIVIDUAL ☒ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

NAME :
ADDRESS :

☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING : Thomas R. Kurz
TITLE OF PERSON OTHER THAN OWNER : General Manager
ADDRESS OF PERSON SIGNING : 15 Catherwood Road
Ithaca, New York 14850

SIGNATURE: Thomas R. Kurz

DATE: MARCH 12, 1999

001-550260

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:)
)
 J. Moon et al.)
)
 Divisional of)
 Serial No.: 09/156,507) Art Unit
) 1741
 Filed: September 17, 1998)
)
 For: INTEGRATED MONOLITHIC MICROFABRICATED)
 ELECTROSPRAY AND LIQUID)
 CHROMATOGRAPHY SYSTEM AND METHOD)
)
 Examiner: Thao Tran)

PRELIMINARY AMENDMENT

Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicant hereby cancels the following claims as originally filed: Claims 1-9; 10; 11-12; 13-16; 18-20; 21 and 22 without prejudice.

REMARKS

This is a divisional patent application directed to Group V consisting of Claim 17, as established in an Office Action dated the 26th of September, 2000 in which the Examiner established a Restriction Requirement.

Dated this 31st day of October, 2000.

Respectfully submitted,



David O. Seeley
Attorney for Applicants
Reg. No. 30,148

WORKMAN, NYDEGGER & SEELEY
1000 Eagle Gate Tower
60 East South Temple
Salt Lake City, Utah 84111
Telephone: (801) 533-9800
Facsimile: (801) 328-1707

G:\DATA\WPDOCS3\CM\14917.1.4 Prelim Amd DOC

Express Mailing Label No. EL675131575US

PATENT APPLICATION
Docket No. 14917.1.4

UNITED STATES PATENT APPLICATION

of

James E. Moon

Gary A. Schultz

Thomas N. Corso

Timothy J. Davis

Gregory J. Galvin

and

Stephen Lowes

for

INTEGRATED MONOLITHIC MICROFABRICATED ELECTROSPRAY AND LIQUID CHROMATOGRAPHY SYSTEM AND METHOD

WORKMAN, NYDEGGER & SEELEY

A PROFESSIONAL CORPORATION
ATTORNEYS AT LAW
1000 EAGLE GATE TOWER
60 EAST SOUTH TEMPLE
SALT LAKE CITY, UTAH 84111

Variable	Mean	SD	Min	Max
Age	35.2	12.5	18	65
Gender	50% Male			
Education	12.5	1.5	9	16
Income	\$25,000	\$10,000	\$10,000	\$50,000
Marital Status	60% Married			
Health Status	75% Good			
Exercise Frequency	2.5 times/week	1.5	0	5
Diet Quality	3.5	1.0	1	5
Stress Level	4.0	1.5	1	5
Sleep Quality	3.0	1.0	1	5
Work Satisfaction	3.5	1.0	1	5
Life Satisfaction	4.0	1.0	1	5
Overall Health Score	70.0	10.0	50	90

1 This application is a divisional of U.S. Application Serial No. 09/156,507 filed
2 September 17, 1998.

3 FIELD OF THE INVENTION

4 The present invention relates generally to an integrated miniaturized chemical
5 analysis system fabricated using microelectromechanical systems (MEMS) technology. In
6 particular, the present invention relates to an integrated monolithic microfabricated
7 electrospray and liquid chromatography device. This achieves a significant advantage in
8 terms of high-throughput analysis by mass spectrometry, as used, for example, in drug
9 discovery, in comparison to a conventional system.

10 BACKGROUND OF THE INVENTION

11 New developments in drug discovery and development are creating new demands
12 on analytical techniques. For example, combinatorial chemistry is often employed to
13 discover new lead compounds. or to create variations of a lead compound. Combinatorial
14 chemistry techniques can generate thousands or millions of compounds (combinatorial
15 libraries) in a relatively short time (on the order of days to weeks). Testing such a large
16 number of compounds for biological activity in a timely and efficient manner requires high-
17 throughput screening methods which allow rapid evaluation of the characteristics of each
18 candidate compound.

19 The compounds in combinatorial libraries are often tested simultaneously against
20 a molecular target. For example, an enzyme assay employing a colorimetric measurement
21 may be run in a 96-well plate. An aliquot of enzyme in each well is combined with tens or
22 hundreds of compounds. An effective enzyme inhibitor will prevent development of color
23 due to the normal enzyme reaction, allowing for rapid spectroscopic (or visual) evaluation
24 of assay results. If ten compounds are present in each well, 960 compounds can be screened
25 in the entire plate, and one hundred thousand compounds can be screened in 105 plates,
26 allowing for rapid and automated testing of the compounds.

Often, however, determination of which compounds are present in certain portions
of a combinatorial library is difficult, due to the manner of synthesis of the library. For
example, the "split-and-pool" method of random peptide synthesis in U.S. Pat. No.
5,182,366, describes a way of creating a peptide library where each resin bead carries a
unique peptide sequence. Placing ten beads in each well of a 96-well plate, followed by
cleavage of the peptides from the beads and removal of the cleavage solution, would result

1 in ten (or fewer) peptides in each well of the plate. Enzyme assays could then be carried out
2 in the plate wells, allowing 100,000 peptides to be screened in 105 plates. However, the
identity of the peptides would not be known, requiring analysis of the contents of each well.

3 The peptides could be analyzed by removing a portion of solution from each well
4 and injecting the contents into a separation device such as liquid chromatography or capillary
5 electrophoresis instrument coupled to a mass spectrometer. Assuming that such a method
6 would take approximately 5 minutes per analysis, it would require over a month to analyze
the contents of 105 96-well plates, assuming the method was fully automated and operating
7 24 hours a day.

8 This example illustrates the critical need for a method for rapid analysis of large
9 numbers of compounds or complex mixtures of compounds, particularly in the context of
high-throughput screening. Techniques for generating large numbers of compounds, for
10 example through combinatorial chemistry, have been established. High-throughput
screening methods are under development for a wide variety of targets, and some types of
11 screens, such as the colorimetric enzyme assay described above and ELISA (enzyme linked
12 immunosorbent assay) technology, are well-established. As indicated in the example above,
13 a bottleneck often occurs at the stage where multiple mixtures of compounds, or even
multiple individual compounds, must be characterized.

14 This need is further underscored when current developments in molecular
15 biotechnology are considered. Enormous amounts of genetic sequence data are being
16 generated through new DNA sequencing methods. This wealth of new information is
17 generating new insights into the mechanism of disease processes. In particular, the
18 burgeoning field of genomics has allowed rapid identification of new targets for drug
development efforts. Determination of genetic variations between individuals has opened
19 up the possibility of targeting drugs to individuals based on the individual's particular genetic
20 profile. Testing for cytotoxicity, specificity, and other pharmaceutical characteristics could
be carried out in high-throughput assays instead of expensive animal testing and clinical
21 trials. Detailed characterization of a potential drug or lead compound early in the drug
22 development process thus has the potential for significant savings both in time and expense.

23 Development of viable screening methods for these new targets will often depend
24 on the availability of rapid separation and analysis techniques for analyzing the results of
assays. For example, an assay for potential toxic metabolites of a candidate drug would need
25 to identify both the candidate drug and the metabolites of that candidate. An assay for
26

1 specificity would need to identify compounds which bind differentially to two molecular
2 targets such as a viral protease and a mammalian protease.

3 It would therefore be advantageous to provide a method for efficient proteomic
4 screening in order to obtain the pharmacokinetic profile of a drug early in the evaluation
5 process. An understanding of how a new compound is absorbed in the body and how it is
6 metabolized can enable prediction of the likelihood for an increased therapeutic effect or lack
7 thereof.

8 Given the enormous number of new compounds that are being generated daily, an
9 improved system for identifying molecules of potential therapeutic value for drug discovery
10 is also critically needed.

11 It also would be desirable to provide rapid sequential analysis and identification of
12 compounds which interact with a gene or gene product that plays a role in a disease of
13 interest. Rapid sequential analysis can overcome the bottleneck of inefficient and time-
14 consuming serial (one-by-one) analysis of compounds.

15 Accordingly, there is a critical need for high-throughput screening and identification
16 of compound-target reactions in order to identify potential drug candidates.

17 Microchip-based separation devices have been developed for rapid analysis of large
18 numbers of samples. Compared to other conventional separation devices, these microchip-
19 based separation devices have higher sample throughput, reduced sample and reagent
20 consumption and reduced chemical waste. The liquid flow rates for microchip-based
21 separation devices range from approximately 1-300 nanoliters (nL) per minute for most
22 applications.

23 Examples of microchip-based separation devices include those for capillary
24 electrophoresis (CE), capillary electrochromatography (CEC) and high-performance liquid
25 chromatography (HPLC). See Harrison *et al.*, Science 1993, 261, 859-897; Jacobson *et al.*
26 Anal. Chem. 1994, 66, 1114-1118; and Jacobson *et al.* Anal. Chem. 1994, 66, 2369-2373.
Such separation devices are capable of fast analyses and provide improved precision and
reliability compared to other conventional analytical instruments.

Liquid chromatography (LC) is a well-established analytical method for separating
components of a fluid for subsequent analysis and/or identification. Traditionally, liquid
chromatography utilizes a separation column, such as a cylindrical tube, filled with tightly
packed beads, gel or other appropriate particulate material to provide a large surface area.
The large surface area facilitates fluid interactions with the particulate material, and the
tightly packed, random spacing of the particulate material forces the liquid to travel over a

1 much longer effective path than the length of the column. In particular, the components of
2 the fluid interact with the stationary phase (the particles in the liquid chromatography
3 column) as well as the mobile phase (the liquid eluent flowing through the liquid
4 chromatography column) based on the partition coefficients for each of the components. The
5 partition coefficient is defined as the ratio of the time an analyte spends interacting with
6 the stationary phase to the time spent interacting with the mobile phase. The longer an
7 analyte interacts with the stationary phase, the higher the partition coefficient and the longer
8 the analyte is retained on the liquid chromatography column. The components may be
9 detected spectroscopically after elution from the liquid chromatography column by coupling
10 the exit of the column to a post-column detector.

11 Spectroscopic detectors rely on a change in refractive index, ultraviolet and/or
12 visible light absorption, or fluorescence after excitation with a suitable wavelength to detect
13 the separated components. Alternatively, the separated components may be passed from the
14 liquid chromatography column into other types of analytical instruments for analysis. The
15 analysis outcome depends upon the sequenced arrival of the components separated by the
16 liquid chromatography column and is therefore time-dependent.

17 The length of liquid transport from the liquid chromatography column to the analysis
18 instrument such as the detector is preferably minimized in order to minimize diffusion and
19 thereby maximize the separation efficiency and analysis sensitivity. The transport length is
20 referred to as the dead volume or extra-column volume.

21 Capillary electrophoresis is a technique that utilizes the electrophoretic nature of
22 molecules and/or the electroosmotic flow of fluids in small capillary tubes to separate
23 components of a fluid. Typically a fused silica capillary of 100 μm inner diameter or less is
24 filled with a buffer solution containing an electrolyte. Each end of the capillary is placed in
25 a separate fluidic reservoir containing a buffer electrolyte.

26 A potential voltage is placed in one of the buffer reservoirs and a second potential
voltage is placed in the other buffer reservoir. Positively and negatively charged species will
migrate in opposite directions through the capillary under the influence of the electric field
established by the two potential voltages applied to the buffer reservoirs. Electroosmotic
flow is defined as the fluid flow along the walls of a capillary due to the migration of charged
species from the buffer solution. Some molecules exist as charged species when in solution
and will migrate through the capillary based on the charge-to-mass ratio of the molecular
species. This migration is defined as electrophoretic mobility. The electroosmotic flow and
the electrophoretic mobility of each component of a fluid determine the overall migration for

1 each fluidic component. The fluid flow profile resulting from electroosmotic flow is flat due
2 to the reduction in frictional drag along the walls of the separation channel. This results in
3 improved separation efficiency over liquid chromatography where the flow profile is
parabolic resulting from pressure driven flow.

4 Capillary electrochromatography is a hybrid technique which utilizes the electrically
5 driven flow characteristics of electrophoretic separation methods within capillary columns
6 packed with a solid stationary phase typical of liquid chromatography. It couples the
7 separation power of reversed-phase liquid chromatography with the high efficiencies of
8 capillary electrophoresis. Higher efficiencies are obtainable for capillary electro-
9 chromatography separations over liquid chromatography because the flow profile resulting
10 from electroosmotic flow is flat due to the reduction in frictional drag along the walls of the
11 separation channel when compared to the parabolic flow profile resulting from pressure
12 driven flows. Furthermore, smaller particle sizes can be used in capillary
13 electrochromatography than in liquid chromatography because no back pressure is generated
14 by electroosmotic flow. In contrast to electrophoresis, capillary electrochromatography is
15 capable of separating neutral molecules due to analyte partitioning between the stationary and
16 mobile phases of the column particles using a liquid chromatography separation mechanism.

17 The separated product of such separation devices may be introduced as the liquid
18 sample to a device that is used to produce electrospray ionization. The electrospray device
19 may be interfaced to an atmospheric pressure ionization mass spectrometer (API-MS) for
20 analysis of the electrosprayed fluid.

21 A schematic of an electrospray system **50** is shown in FIG. 1. An electrospray is
22 produced when a sufficient electrical potential difference V_{spray} is applied between a
23 conductive or partly conductive fluid exiting a capillary orifice and an electrode so as to
24 generate a concentration of electric field lines emanating from the tip or end of a capillary
25 **52** of an electrospray device. When a positive voltage V_{spray} is applied to the tip of the
26 capillary relative to an extracting electrode **54**, such as one provided at the ion-sampling
orifice to the mass spectrometer, the electric field causes positively-charged ions in the fluid
to migrate to the surface of the fluid at the tip of the capillary. When a negative voltage V_{spray}
is applied to the tip of the capillary relative to an extracting electrode **54**, such as one
provided at the ion-sampling orifice to the mass spectrometer, the electric field causes
negatively-charged ions in the fluid to migrate to the surface of the fluid at the tip of the
capillary.

1 When the repulsion force of the solvated ions exceeds the surface tension of the fluid
2 sample being electrosprayed, a volume of the fluid sample is pulled into the shape of a cone,
3 known as a Taylor cone **56** which extends from the tip of the capillary. Small charged
4 droplets **58** are formed from the tip of the Taylor cone **56** and are drawn toward the
5 extracting electrode **54**. This phenomenon has been described, for example, by Dole et al.,
6 *Chem. Phys.* 1968, 49, 2240 and Yamashita and Fenn, *J. Phys. Chem.* 1984, 88, 4451. The
7 potential voltage required to initiate an electrospray is dependent on the surface tension of
8 the solution as described by, for example, Smith, *IEEE Trans. Ind. App.* 1986, IA-22, 527-
9 535. Typically, the electric field is on the order of approximately 10^6 V/m. The physical
10 size of the capillary determines the density of electric field lines necessary to induce
11 electrospray.

12 One advantage of electrospray ionization is that the response for an analyte measured
13 by the mass spectrometer detector is dependent on the concentration of the analyte in the
14 fluid and independent of the fluid flow rate. The response of an analyte in solution at a given
15 concentration would be comparable using electrospray ionization combined with mass
16 spectrometry at a flow rate of $100\ \mu\text{L}/\text{min}$ compared to a flow rate of $100\ \text{nL}/\text{min}$.

17 The process of electrospray ionization at flow rates on the order of nanoliters per
18 minute has been referred to as "nanoelectrospray". Electrospray into the ion-sampling orifice
19 of an API mass spectrometer produces a quantitative response from the mass spectrometer
20 detector due to the analyte molecules present in the liquid flowing from the capillary.

21 Thus, it is desirable to provide an electrospray ionization device for integration
22 upstream with microchip-based separation devices and for integration downstream with API-
23 MS instruments.

24 Attempts have been made to manufacture an electrospray device which produces
25 nanoelectrospray. For example, Wilm and Mann, *Anal. Chem.* 1996, 68, 1-8 describes the
26 process of electrospray from fused silica capillaries drawn to an inner diameter of $2\text{-}4\ \mu\text{m}$ at
flow rates of $20\ \text{nL}/\text{min}$. Specifically, a nanoelectrospray at $20\ \text{nL}/\text{min}$ was achieved from
a $2\ \mu\text{m}$ inner diameter and $5\ \mu\text{m}$ outer diameter pulled fused-silica capillary with 600-700
V at a distance of 1-2 mm from the ion-sampling orifice of an API mass spectrometer.

Ramsey et al., *Anal. Chem.* 1997, 69, 1174-1178 describes nanoelectrospray at $90\ \text{nL}/\text{min}$
from the edge of a planar glass microchip with a closed separation channel $10\ \mu\text{m}$
deep, $60\ \mu\text{m}$ wide and 33 mm in length using electroosmotic flow and applying 4.8 kV to the
fluid exiting the closed separation channel on the edge of the microchip for electrospray
formation, with the edge of the chip at a distance of 3-5 mm from the ion-sampling orifice

1 of an API mass spectrometer. Approximately 12 nL of the sample fluid collects at the edge
2 of the chip before the formation of a Taylor cone and stable nanoelectrospray from the edge
3 of the microchip. However, collection of approximately 12 nL of the sample fluid will result
4 in remixing of the fluid, thereby undoing the separation done in the separation channel.
5 Remixing causes band broadening at the edge of the microchip, fundamentally limiting its
6 applicability for nanoelectrospray-mass spectrometry for analyte detection. Thus,
7 nanoelectrospray from the edge of this microchip device after capillary electrophoresis or
8 capillary electrochromatography separation is rendered impractical. Furthermore, because
9 this device provides a flat surface, and thus a relatively small amount of physical asperity,
10 for the formation of the electrospray, the device requires an impractically high voltage to
11 initiate electrospray, due to poor field line concentration.

12 Xue, Q.; Foret, F.; Dunayevskiy, Y. M.; Zavracky, P. M.; McGruer, N.E.; Karger,
13 B. L. *Anal. Chem.* 1997, 69, 426-430 describes a stable nanoelectrospray from the edge of
14 a planar glass microchip with a closed channel 25 μm deep, 60 μm wide and 35-50 mm in
15 length and applying 4.2 kV to the fluid exiting the closed separation channel on the edge of
16 the microchip for electrospray formation, with the edge of the chip at a distance of 3-8 mm
17 from the ion-sampling orifice of an API mass spectrometer. A syringe pump is utilized to
18 deliver the sample fluid to the glass microchip electrosprayer at a flow rate between 100-200
19 nL/min. The edge of the glass microchip is treated with a hydrophobic coating to alleviate
20 some of the difficulties associated with nanoelectrospray from a flat surface and which
21 slightly improves the stability of the nanoelectrospray. Electrospraying in this manner from
22 a flat surface again results in poor field line concentration and yields an inefficient
23 electrospray.

24 Desai et al. 1997 *International Conference on Solid-State Sensors and Actuator*,
25 Chicago, June 16-19, 1997, 927-930 describes a multi-step process to generate a nozzle on
26 the edge of a silicon microchip 1-3 μm in diameter or width and 40 μm in length and
applying 4 kV to the entire microchip at a distance of 0.25-0.4 mm from the ion-sampling
orifice of an API mass spectrometer. This nanoelectrospray nozzle reduces the dead volume
of the sample fluid. However, the extension of the nozzle from the edge of the microchip
exposes the nozzle to accidental breakage. Because a relatively high spray voltage was
utilized and the nozzle was positioned in very close proximity to the mass spectrometer
sampling orifice, a poor field line concentration and a low efficient electrospray were
achieved.

In all of the above-described devices, edge-spraying from a monolithic chip is a

1 poorly controlled process due to the inability to rigorously and repeatably determine the
2 physical form of the chip's edge. In another embodiment of edge-spraying, ejection nozzles,
3 such as small segments of drawn capillaries, are separately and individually attached to the
4 chip's edge. This process is inherently cost-inefficient and unreliable, imposes space
constraints in chip design, and is therefore unsuitable for manufacturing.

5 Thus, it is also desirable to provide an electrospray ionization device with
6 controllable spraying and a method for producing such a device which is easily reproducible
and manufacturable in high volumes.

7 8 SUMMARY OF THE INVENTION

9 The present invention provides a silicon microchip-based electrospray device for
10 producing reproducible, controllable and robust nanoelectrospray ionization of a liquid
11 sample. The electrospray device may be interfaced downstream to an atmospheric pressure
12 ionization mass spectrometer (API-MS) for analysis of the electrosprayed fluid and/or
interfaced upstream to a miniaturized liquid phase separation device, which may have, for
example, glass, plastic or silicon substrates or wafers.

13 The electrospray device of the present invention generally comprises a silicon
14 substrate or microchip defining a channel between an entrance orifice on an injection surface
15 and a nozzle on an ejection surface (the major surface) such that the electrospray generated
16 by the electrospray device is generally approximately perpendicular to the ejection surface.
17 The nozzle has an inner and an outer diameter and is defined by an annular portion recessed
from the ejection surface. The annular recess extends radially from the outer diameter. The
tip of the nozzle is co-planar or level with and does not extend beyond the ejection surface
and thus the nozzle is protected against accidental breakage. The nozzle, channel and
18 recessed portion are etched from the silicon substrate by reactive-ion etching and other
19 standard semiconductor processing techniques.

20 All surfaces of the silicon substrate preferably have a layer of silicon dioxide thereon
21 created by oxidization to electrically isolate the liquid sample from the substrate and the
22 ejection and injection surfaces from each other such that different potential voltages may be
23 individually applied to each surface and the liquid sample. The silicon dioxide layer also
24 provides for biocompatibility. The electrospray apparatus further comprises at least one
controlling electrode electrically contacting the substrate through the oxide layer for the
25 application of an electric potential to the substrate.

1 Preferably, the nozzle, channel and recess are etched from the silicon substrate by
2 reactive-ion etching and other standard semiconductor processing techniques. The injection-
3 side feature(s), through-substrate fluid channel, ejection-side features, and controlling
4 electrodes - are formed monolithically from a monocrystalline silicon substrate. That is, they
5 are formed during the course of and as a result of a fabrication sequence that requires no
manipulation or assembly of separate components.

6 Because the electrospray device is manufactured using reactive-ion etching and other
7 standard semiconductor processing techniques, the dimensions of such a device can be very
8 small, for example, as small as 2 μm inner diameter and 5 μm outer diameter. Thus, a nozzle
9 having, for example, 5 μm inner diameter and 250 μm in height only has a volume of 4.9 pL
10 (picoliter). In contrast, an electrospray device from the flat edge of a glass microchip would
11 introduce additional dead volume of 12 nL compared to the volume of a separation channel
12 of 19.8 nL thereby allowing remixing of the fluid components and undoing the separation
done by the separation channel. The micrometer-scale dimensions of the electrospray device
minimizes the dead volume and thereby increases efficiency and analysis sensitivity.

13 The electrospray device of the present invention provides for the efficient and
14 effective formation of an electrospray. By providing an electrospray surface from which the
15 fluid is ejected with dimensions on the order of micrometers, the electrospray device limits
16 the voltage required to generate a Taylor cone as the voltage is dependent upon the nozzle
17 diameter, surface tension of the fluid and the distance of the nozzle from the extracting
18 electrode. The nozzle of the electrospray device provides the physical asperity on the order
19 of micrometers on which a large electric field is concentrated. Further, the electrospray
20 device may provide additional electrode(s) on the ejecting surface to which electric
21 potential(s) may be applied and controlled independent of the electric potentials of the fluid
22 and the extracting electrode in order to advantageously modify and optimize the electric
23 field. The combination of the nozzle and the additional electrode(s) thus enhance the electric
24 field between the nozzle and the extracting electrode. The large electric field, on the order
25 of 10^6 V/m or greater and generated by the potential difference between the fluid and
26 extracting electrode, is thus applied directly to the fluidic cone rather than uniformly
distributed in space.

The microchip-based electrospray ionization device of the present invention
provides minimal extra-column dispersion as a result of a reduction in the extra-column
volume and provides efficient, reproducible, reliable and rugged formation of an
electrospray. The design of the ionization device is also robust such that the electrospray

1 device can be readily mass-produced in a cost-effective, high-yielding process.

2 In operation, a conductive or partly conductive liquid sample is introduced into the
3 channel through the entrance orifice on the injection surface. The liquid sample and nozzle
4 are held at the potential voltage applied to the fluid, either by means of a wire within the fluid
5 delivery channel to the electrospray device or by means of an electrode formed on the
6 injection surface isolated from the surrounding surface region and from the substrate. The
7 electric field strength at the tip of the nozzle is enhanced by the application of a voltage to
8 the substrate and/or the ejection surface, preferably approximately less than one-half of the
9 voltage applied to the fluid. Thus, by the independent control of the fluid/nozzle and
10 substrate/ejection surface voltages, the electrospray device of the present invention allows
11 the optimization of the electric field lines emanating from the nozzle. Further, when the
12 electrospray device is interfaced downstream with a mass spectrometry device, the
13 independent control of the fluid/nozzle and substrate/ejection surface voltages also allows
14 for the direction and optimization of the electrospray into an acceptance region of the mass
15 spectrometry device.

16 The electrospray device of the present invention may be placed 1-2 mm or up to 10
17 mm from the orifice of an API mass spectrometer to establish a stable nanoelectrospray at
18 flow rates as low as 20 nL/min with a voltage of, for example, 700 V applied to the nozzle
19 and 0-350 V applied to the substrate and/or the planar ejection surface of the silicon
20 microchip.

21 An array or matrix of multiple electrospray devices of the present invention may be
22 manufactured on a single microchip as silicon fabrication using standard, well-controlled
23 thin-film processes not only eliminates handling of such micro components but also allows
24 for rapid parallel processing of functionally alike elements. The nozzles may be radially
25 positioned about a circle having a relatively small diameter near the center of the chip. Thus,
26 the electrospray device of the present invention provides significant advantages of time and
cost efficiency, control, and reproducibility. The low cost of these electrospray devices
allows for one-time use such that cross-contamination from different liquid samples may be
eliminated.

The electrospray device of the present invention can be integrated upstream with
miniaturized liquid sample handling devices and integrated downstream with an API mass
spectrometer. The electrospray device may be chip-to-chip or wafer-to-wafer bonded to
silicon microchip-based liquid separation devices capable of, for example, capillary
electrophoresis, capillary electrochromatography, affinity chromatography, liquid

1 chromatography (LC) or any other condensed-phase separation technique. The electrospray
2 device may be alternatively bonded to glass-and/or polymer-based liquid separation devices
3 with any suitable method.

4 In another aspect of the invention, a microchip-based liquid chromatography
5 device may be provided. The liquid chromatography device generally comprises a separation
6 substrate or wafer defining an introduction channel between an entrance orifice and a
7 reservoir and a separation channel between the reservoir and an exit orifice. The separation
8 channel is populated with separation posts extending from a side wall of the separation
9 channel perpendicular to the fluid flow through the separation channel. Preferably, the
10 separation posts do not extend beyond and are preferably coplanar or level with the surface
11 of the separation substrate such that they are protected against accidental breakage during the
12 manufacturing process. Component separation occurs in the separation channel where the
13 separation posts perform the liquid chromatography function by providing large surface areas
14 for the interaction of fluid flowing through the separation channel. A cover substrate may
15 be bonded to the separation substrate to enclose the reservoir and the separation channel
16 adjacent the cover substrate.

17 The liquid chromatography device may further comprise one or more electrodes for
18 application of electric potentials to the fluid at locations along the fluid path. The application
19 of different electric potentials along the fluid path may facilitate the fluid flow through the
20 fluid path.

21 The introduction and separation channels, the entrance and exit orifices and the
22 separation posts are preferably etched from a silicon substrate by reactive-ion etching and
23 other standard semiconductor processing techniques. The separation posts are preferably
24 oxidized silicon posts which may be chemically modified to optimize the interaction of the
25 components of the sample fluid with the stationary separation posts.

26 In another aspect of the invention, the liquid chromatography device may be
integrated with the electrospray device such that the exit orifice of the liquid chromatography
device forms a homogenous interface with the entrance orifice of the electrospray device,
thereby allowing the on-chip delivery of fluid from the liquid chromatography device to the
electrospray device to generate an electrospray. The nozzle, channel and recessed portion
of the electrospray device may be etched from the cover substrate of the liquid
chromatography device.

In yet another aspect of the invention, multiples of the liquid chromatography-
electrospray system may be formed on a single chip to deliver a multiplicity of samples to

1 a common point for subsequent sequential analysis. The multiple nozzles of the electrospray
2 devices may be radially positioned about a circle having a relatively small diameter near the
center of the single chip.

3 The radially distributed array of electrospray nozzles on a multi-system chip may be
4 interfaced with a sampling orifice of a mass spectrometer by positioning the nozzles near the
5 sample orifice. The tight radial configuration of the electrospray nozzles allows the
6 positioning thereof in close proximity to the sampling orifice of a mass spectrometer.

7 The multi-system chip thus provides a rapid sequential chemical analysis system
8 fabricated using microelectromechanical systems (MEMS) technology. For example, the
9 multi-system chip enables automated, sequential separation and injection of a multiplicity
10 of samples, resulting in significantly greater analysis throughput and utilization of the mass
spectrometer instrument for, for example, high-throughput detection of compounds for drug
discovery.

11 BRIEF DESCRIPTION OF THE DRAWINGS

12 The file of this patent contains at least one drawing executed in color. Copies of this
13 patent with color drawings will be provided by the Patent and Trademark Office upon request
14 and payment of the necessary fee.

15 FIG. 1 shows a schematic of an electrospray system;

16 FIG. 2 shows a perspective view of an electrospray device of the present invention;

17 FIG. 3 shows a plan view of the electrospray device of FIG. 2;

18 FIG. 4 shows a cross-sectional view of the electrospray device of FIG. 3 taken along
line 4-4;

19 FIG. 5 shows a schematic of an electrospray system comprising an electrospray
device of the present invention;

20 FIG. 6 shows a plan view of an electrospray device having multiple electrodes on
the ejection surface of the device;

21 FIG. 7 shows a cross-sectional view of the electrospray device of FIG. 6 taken along
22 line 7-7;

23 FIG. 8 illustrates a feedback control circuit incorporating an electrospray device of
the present invention;

24 FIGS. 9-20G show an example of a fabrication sequence of the electrospray device;

1 FIG. 21 A shows a cross-sectional view of a piezoelectric pipette positioned at a
2 distance from and for delivery of a fluid sample to the entrance orifice of the electrospray
device;

3 FIG. 21 B shows a cross-sectional view of a capillary for delivery of a fluid sample
4 to and prior to attachment to the entrance orifice of the electrospray device;

5 FIG. 22 shows a schematic of a single integrated system comprising an upstream
6 fluid delivery device and an electrospray device having a homogeneous interface with the
fluid delivery device;

7 FIG. 23A shows an exploded perspective view of a chip-based combinatorial
8 chemistry system comprising a reaction well block and a daughter plate;

9 FIG. 23B shows a cross-sectional view of the chip-based combinatorial chemistry
system of FIG. 23A taken along line 23B-23B;

10 FIGS. 24A and 24B shows a real Taylor cone emanating from an integrated silicon
11 chip-based nozzle;

12 FIGS. 24C and 24D are perspective and side cross-sectional views, respectively, of
the electrospray device and mass spectrometry system of FIGS. 24A and 24B;

13 FIG. 24E shows a mass spectrum of 1 $\mu\text{g/mL}$ PPG425 in 50% water, 50% methanol
14 containing 0.1% formic acid, 0.1% acetonitrile and 2 mM ammonium acetate, collected at
a flow rate of 333 nL/min;

15 FIG. 25A shows an exploded perspective view of a liquid chromatography device
16 for homogeneous integration with the electrospray device of the present invention;

17 FIG. 25B shows a cross-sectional view of the liquid chromatography device of FIG.
25A taken along line 25B-25B;

18 FIG. 26 shows a plan view of a liquid chromatography device having an exit orifice
19 forming an off-chip interconnection with an off-chip device;

20 FIG. 27 shows a plan view of a liquid chromatography device having an exit orifice
forming an on-chip interconnection with another on-chip device;

21 FIGS. 28-29 show cross-sectional views of liquid chromatography devices having
22 alternative configurations;

23 FIGS. 30-35 show plan views of liquid chromatography devices having alternative
configurations;

24 FIGS. 36A-46C show an example of a fabrication sequence of the liquid
25 chromatography device;

26

1 FIG. 47 shows a cross-sectional view of a system comprising a liquid
2 chromatography device homogenously integrated with an electrospray device;
3 FIG. 48 shows a plan view of the system of FIG. 47; and
4 FIG. 49 shows a detailed view of the nozzles of the system of FIG. 47.

5 DETAILED DESCRIPTION OF THE INVENTION

6 An aspect of the present invention provides a silicon microchip-based electrospray
7 device for producing electrospray ionization of a liquid sample. The electrospray device may
8 be interfaced downstream to an atmospheric pressure ionization mass spectrometer (API-
9 MS) for analysis of the electrosprayed fluid. Another aspect of the invention is an integrated
10 miniaturized liquid phase separation device, which may have, for example, glass, plastic or
11 silicon substrates integral with the electrospray device. The descriptions that follow present
12 the invention in the context of a liquid chromatograph separation device. However, it will
13 be readily recognized that equivalent devices can be made that utilize other microchip-based
14 separation devices. The following description is presented to enable any person skilled in the
15 art to make and use the invention. Descriptions of specific applications are provided only as
16 examples. Various modifications to the preferred embodiment will be readily apparent to
17 those skilled in the art, and the general principles defined herein may be applied to other
18 embodiments and applications without departing from the spirit and scope of the invention.
19 Thus, the present invention is not intended to be limited to the embodiments shown, but is
20 to be accorded the widest scope consistent with the principles and features disclosed herein.

21 **ELECTROSPRAY DEVICE**

22 FIGS. 2-4 show, respectively, a perspective view, a plan view and a crosssectional
23 view of an electrospray device **100** of the present invention. The electrospray apparatus of
24 the present invention generally comprises a silicon substrate or microchip or wafer **102**
25 defining a channel **104** through substrate **102** between an entrance orifice **106** on an injection
26 surface **108** and a nozzle **110** on an ejection surface **112**. The channel may have any suitable
cross-sectional shape such as circular or rectangular. The nozzle **110** has an inner and an
outer diameter and is defined by a recessed region **114**. The region **114** is recessed from the
ejection surface **112**, extends outwardly from the nozzle **110** and may be annular. The tip
of the nozzle **110** does not extend beyond and is preferably coplanar or level with the ejection
surface **112** to thereby protect the nozzle **110** from accidental breakage.

Preferably, the injection surface **108** is opposite the ejection surface **112**. However,
although not shown, the injection surface may be adjacent to the ejection surface such that

1 the channel extending between the entrance orifice and the nozzle makes a turn within the
2 device. In such a configuration, the electrospray device would comprise two substrates
3 bonded together. The first substrate may define a through-substrate channel extending
4 between a bonding surface and the ejection surface, opposite the bonding surface. The first
5 substrate may further define an open channel recessed from the bonding surface extending
6 from an orifice of the through-substrate channel and the injection surface such that the
7 bonding surface of the second substrate encloses the open channel upon bonding of the first
8 and second substrates. Alternatively, the second substrate may define an open channel
9 recessed from the bonding surface such that the bonding surface of the first substrate
10 encloses the open channel upon bonding of the first and second substrates. In yet another
11 variation, the first substrate may further define a second through-substrate channel while the
12 open channel extends between the two through-substrate channels. Thus, the injection
13 surface is the same surface as the ejection surface.

14 A grid-plane region **116** of the ejection surface **112** is exterior to the nozzle **110** and
15 to the recessed region **114** and may provide a surface on which a layer of conductive material
16 **119**, including a conductive electrode **120**, may be formed for the application of an electric
17 potential to the substrate **102** to modify the electric field pattern between the ejection surface
18 **112**, including the nozzle tip **110**, and the extracting electrode **54**. Alternatively, the
19 conductive electrode may be provided on the injection surface **108** (not shown).

20 The electrospray device **100** further comprises a layer of silicon dioxide **118** over
21 the surfaces of the substrate **102** through which the electrode **120** is in contact with the
22 substrate **102** either on the ejection surface **112** or on the injection surface **108**. The silicon
23 dioxide **118** formed on the walls of the channel **104** electrically isolates a fluid therein from
24 the silicon substrate **102** and thus allows for the independent application and sustenance of
25 different electrical potentials to the fluid in the channel **104** and to the silicon substrate **102**.
26 The ability to independently vary the fluid and substrate potentials allows the optimization
of the electrospray through modification of the electric field line pattern, as described below.
Alternatively, the substrate **102** can be controlled to the same electrical potential as the fluid
when appropriate for a given application.

As shown in FIG. 5, to generate an electrospray, fluid may be delivered to the
entrance orifice **106** of the electrospray device **100** by, for example, a capillary **52** or
micropipette. The fluid is subjected to a potential voltage V_{fluid} via a wire (not shown)
positioned in the capillary **52** or in the channel **104** or via an electrode (not shown) provided
on the injection surface **108** and isolated from the surrounding surface region and the

1 substrate **102**. A potential voltage $V_{\text{substrate}}$ may also be applied to the electrode **120** on the
2 grid-plane **116**, the magnitude of which is preferably adjustable for optimization of the
3 electrospray characteristics. The fluid flows through the channel **104** and exits or is ejected
4 from the nozzle **110** in the form of very fine, highly charged fluidic droplets **58**. The
5 electrode **54** may be held at a potential voltage V_{extract} such that the electrospray is drawn
6 toward the extracting electrode **54** under the influence of an electric field. As it is the
7 relative electric potentials which affect the electric field, the potential voltages of the fluid,
8 the substrate and the extracting electrode may be easily adjusted and modified to achieve the
9 desired electric field. Generally, the magnitude of the electric field should not exceed the
10 dielectric breakdown strength of the surrounding medium, typically air.

11 In one embodiment, the nozzle **110** may be placed up to 10 mm from the sampling
12 orifice of an API mass spectrometer serving as the extracting electrode **54**. A potential
13 voltage V_{fluid} ranging from approximately 500-1000 V, such as 700 V, is applied to the fluid.
14 The potential voltage of the fluid V_{fluid} may be up to 500 V/ μm of silicon dioxide on the
15 surface of the substrate **102** and may depend on the surface tension of the fluid being sprayed
16 and the geometry of the nozzle **110**. A potential voltage of the substrate $V_{\text{substrate}}$ of
17 approximately less than half of the fluid potential voltage V_{fluid} , or 0-350 V, is applied to the
18 electrode on the grid-plane **116** to enhance the electric field strength at the tip of the nozzle
19 **110**. The extracting electrode **54** may be held at or near ground potential V_{extract} (0 V). Thus,
20 a nanoelectrospray of a fluid introduced to the electrospray device **100** at flow rates less than
21 1,000 nL/min is drawn toward the extracting electrode **54** under the influence of the electric
22 field.

23 The nozzle **110** provides the physical asperity for concentrating the electric field
24 lines emanating from the nozzle **110** in order to achieve efficient electrospray. The nozzle
25 **110** also forms a continuation of and serves as an exit orifice of the through-substrate channel
26 **104**. Furthermore, the recessed region **114** serves to physically isolate the nozzle **110** from
the grid-plane region **116** of the ejection surface **112** to thereby promote the concentration
of electric field lines and to provide electrical isolation between the nozzle **110** and the grid-
plane region **116**. The present invention allows the optimization of the electric field lines
emanating from the nozzle **110** through independent control of the potential voltage V_{fluid} of
the fluid and nozzle **110** and the potential voltage $V_{\text{substrate}}$ of the electrode on the grid-plane
116 of the ejection surface **112**.

In addition to the electrode **120**, one or more additional conductive electrodes may
be provided on the silicon dioxide layer **118** on the ejection surface **112** of the substrate **102**.

1 FIGS. 6 and 7 show, respectively, a plan view and a cross-sectional view of an example of
2 an electro spray device **100'** wherein the conductive layer **119** defines three additional
3 electrodes **122, 124, 126** on the ejection surface **112** of the substrate **102**. Because the silicon
4 dioxide layer **118** on the ejection surface **112** electrically isolates the silicon substrate **102**
5 from the additional electrodes **122, 124, 126** on the ejection surface **112** and because the
6 additional electrodes **122, 124, 126** are physically separated from each other, the electrical
7 potential applied to each of the additional electrodes **122, 124, 126** can be controlled
8 independently from each other, from the substrate **102** and from the fluid. Thus, additional
9 electrodes **122, 124, 126** may be utilized to further modify the electric field line pattern to
effect, for example, a steering and/or shaping of the electro spray. Although shown to be of
similar sizes and shapes, electrode **120** and additional electrodes **122, 124, 126** may be of any
same or different suitable shapes and sizes.

10 To further control and optimize the electro spray, a feedback control circuit **130** as
11 shown in FIG. 8 may also be provided with the electro spray device **100**. The feedback circuit
12 **130** includes an optimal spray attribute set point **132**, a comparator and voltage control **134**
13 and one or more spray attribute sensors **136**. The optimal spray attribute set point **132** is set
14 by an operator or at a determined or default value. The one or more spray attribute sensors
15 **136** detect one or more desired attributes of the electro spray from the electro spray device
16 **100**, such as the electro spray ion current and/or the spatial concentration of the spray pattern.
17 The spray attribute sensor **136** sends signals indicating the value of the desired attribute of
18 the electro spray to the comparator and voltage control **134** which compares the indicated
19 value of the desired attribute with the optimal spray attribute set point **132**. The comparator
20 and voltage control **134** then applies potential voltages V_{fluid} , $V_{\text{substrate}}$ to the fluid and the
silicon substrate **102**, respectively, which may be independently varied to optimize the
desired electro spray attribute. Although not shown, the comparator and voltage control **134**
may apply independently controlled additional potential voltages to each of one or more
additional conductive electrodes.

21 The feedback circuit **130** may be interfaced with the electro spray device **100** in any
22 suitable fashion. For example, the feedback circuit **130** may be fabricated as an integrated
23 circuit on the electro spray device **100**, as a separate integrated circuit with electrical
24 connection to the electro spray device **100**, or as discrete components residing on a common
substrate electrically connected to the substrate of the electro spray device.

25 Dimensions of the electro spray device **100** can be determined according to various
26 factors such as the specific application, the layout design as well as the upstream and/or

1 downstream device to which the electrospray device **100** is interfaced or integrated. Further,
2 the dimensions of the channel and nozzle may be optimized for the desired flow rate of the
3 fluid sample. The use of reactive-ion etching techniques allows for the reproducible and cost
4 effective production of small diameter nozzles, for example, a 2 μm inner diameter and 5 μm
outer diameter.

5 In one currently preferred embodiment, the silicon substrate **102** of the electrospray
6 device **100** is approximately 250-600 μm in thickness and the cross-sectional area of the
7 channel **104** is less than approximately 50,000 μm^2 . Where the channel **104** has a circular
8 cross-sectional shape, the channel **104** and the nozzle **110** have an inner diameter of up to
9 250 μm , more preferably up to 145 μm ; the nozzle **110** has an outer diameter of up to 255
10 μm , more preferably up to 150 μm ; and nozzle **110** has a height of (and the recessed portion
11 **114** has a depth of) up to 500 μm . The recessed portion **114** preferably extends up to 1000
12 μm outwardly from the nozzle **110**. The silicon dioxide layer **118** has a thickness of
approximately 1-4 μm , preferably 1-2 μm .

13 **ELECTROSPRAY DEVICE FABRICATION PROCEDURE**

14 The fabrication of the electrospray device **100** will now be explained with reference
15 to FIGS. 9-20B. The electrospray device **100** is preferably fabricated as a monolithic silicon
16 integrated circuit utilizing established, well-controlled thin-film silicon processing
17 techniques such as thermal oxidation, photolithography, reactivation etching (RIE), ion
18 implantation, and metal deposition. Fabrication using such silicon processing techniques
19 facilitates massively parallel processing of similar devices, is time- and cost-efficient, allows
20 for tighter control of critical dimensions, is easily reproducible, and results in a wholly
integral device, thereby eliminating any assembly requirements. Further, the fabrication
sequence may be easily extended to create physical aspects or features on the injection
surface and/or ejection surface of the electrospray device to facilitate interfacing and
connection to a fluid delivery system or to facilitate integration with a fluid delivery sub-
system to create a single integrated system.

21 **Injection surface processing: entrance to through-wafer channel**

22 FIGS. 9A-11 illustrate the processing steps for the injection side of the substrate in
23 fabricating the electrospray device **100** of the present invention. Referring to the plan and
24 cross-sectional views, respectively, of FIGS. 9A and 9B, a double-side polished silicon wafer
25 substrate **200** is subjected to an elevated temperature in an oxidizing ambient to grow a layer
26 or film of silicon dioxide **202** on the injection side **203** and a layer or film of silicon dioxide
204 on the ejection side **205** of the substrate **200**. Each of the resulting silicon dioxide layers

1 **202, 204** has a thickness of approximately 1-2 μm . The silicon dioxide layers **202, 204**
2 provide electrical isolation and also serve as masks for subsequent selective etching of
3 certain areas of the silicon substrate **200**.

4 A film of positive-working photoresist **206** is deposited on the silicon dioxide layer
5 **202** on the injection side **203** of the substrate **200**. An area of the photoresist **206**
6 corresponding to the entrance to a through-wafer channel which will be subsequently etched
7 is selectively exposed through a mask by an optical lithographic exposure tool passing short-
8 wavelength light such as blue or near-ultraviolet at wavelengths of 365, 405, or 436
9 nanometers.

10 As shown in the plan and cross-sectional views, respectively, of FIGS. 10A and 10B,
11 after development of the photoresist **206**, the exposed area **208** of the photoresist is removed
12 and open to the underlying silicon dioxide layer **202** while the unexposed areas remain
13 protected by photoresist **206'**. The exposed area **210** of the silicon dioxide layer **202** is then
14 etched by a fluorine-based plasma with a high degree of anisotropy and selectivity to the
15 protective photoresist **206'** until the silicon substrate **200** is reached. The remaining
16 photoresist is removed in an oxygen plasma or in an actively oxidizing chemical bath like
17 sulfuric acid (H_2SO_4) activated with hydrogen peroxide (H_2O_2).

18 As shown in the cross-sectional view of FIG. 11, an injection side portion **212** of the
19 through channel in the silicon substrate **200** is vertically etched by another fluorine-based
20 etch. An advantage of the fabrication process described herein is that the dimensions of the
21 through channel, such as the aspect ratio (depth to width), can be reliably and reproducibly
22 limited and controlled. In the case where the etch aspect ratio of the processing equipment
23 is a limiting factor, it is possible to overcome this limitation by a first etch on one side of a
24 wafer followed by a second etch on a second side of the wafer. For example, a current
25 silicon etch process is generally limited to an etch aspect ratio of 30:1, such that a channel
26 having a diameter less than approximately 10 μm through a substrate **200** having customary
thickness approximately 250-600 μm would be etched from both surfaces of the substrate
200.

The depth of the channel portion **212** should be at or above a minimum in order to
connect with another portion of the through channel etched from the ejection side **205** of the
substrate **200**. The desired depth of the recessed region **114** on the ejection side **205**
determines approximately how far the ejection side portion **220** of the channel **104** is etched.
The remainder of the channel **104**, the injection side portion **212**, is etched from the injection
side. The minimum depth of channel portion **212** is typically 50 μm , although the exact etch

1 depth above the minimum etch depth does not impact the device performance or yield of the
2 electropray device.

Ejection surface processing: nozzle and surrounding surface structure

3 FIGS. 12-20B illustrate the processing steps for the ejection side **205** of the substrate
4 **200** in fabricating the electropray device **100** of the present invention. As shown in the
5 cross-sectional view in FIG. 12, a film of positive-working photoresist **214** is deposited on
6 the silicon dioxide layer **204** on the ejection side **205** of the substrate **200**. Patterns on the
7 ejection side **205** are aligned to those previously formed on the injection side **203** of the
8 substrate **200**. Because silicon and its oxide are inherently relatively transparent to light in
9 the infrared wavelength range of the spectrum, i.e. approximately 70-1000 nanometers, the
10 extant pattern on the injection side **203** can be distinguished with sufficient clarity by
11 illuminating the substrate **200** from the patterned injection side **203** with infrared light. Thus,
12 the mask for the ejection side **205** can be aligned within required tolerances.

13 After alignment, certain areas of the photoresist **214** corresponding to the nozzle and
14 the recessed region are selectively exposed through an ejection side mask by an optical
15 lithographic exposure tool passing short-wavelength light, such as blue or near-ultraviolet
16 at wavelengths of 365, 405, or 436 nanometers. As shown in the plan and cross-sectional
17 views, respectively, of FIGS. 13A and 13B, the photoresist **214** is then developed to remove
18 the exposed areas of the photo resist such that the nozzle area **216** and recessed region area
19 **218** are open to the underlying silicon dioxide layer **204** while the unexposed areas remain
20 protected by photoresist **214'**. The exposed areas **216**, **218** of the silicon dioxide layer **204**
21 are then etched by a fluorine-based plasma with a high degree of anisotropy and selectivity
22 to the protective photoresist **214'** until the silicon substrate **200** is reached.

23 As shown in the cross-sectional view of FIG. 14, the remaining photoresist **214'**
24 provides additional masking during a subsequent fluorine based silicon etch to vertically etch
25 certain patterns into the ejection side **205** of the silicon substrate **200**. The remaining
26 photoresist **214'** is then removed in an oxygen plasma or in an actively oxidizing chemical
bath like sulfuric acid (H_2SO_4) activated with hydrogen peroxide (H_2O_2).

The fluorine-based etch creates a channel **104** through the silicon substrate **200** by
forming an ejection side portion **220** of the channel **104**. The fluorine based etch also creates
an ejection nozzle **110**, a recessed region **114** exterior to the nozzle **110** and a grid-plane
region **116** exterior to the nozzle **110** and to the recessed region **114**. The grid-plane region
116 is preferably co-planar with the tip of the nozzle **110** so as to physically protect the
nozzle **110** from casual abrasion, stress fracture in handling and/or accidental breakage. The

1 grid-plane region **116** also serves as a platform on which one or more conductive electrodes
2 may be provided.

3 The fabrication sequence confers superior mechanical stability to the fabricated
4 electrospray device by etching the features of the electrospray device from a monocrystalline
5 silicon substrate without any need for assembly. The fabrication sequence allows for the
6 control of the nozzle height by adjusting the relative amounts of injection side and ejection
7 side silicon etching. Further, the lateral extent and shape of the recessed region **114** can be
8 controlled independently of its depth, which affects the nozzle height and which is
9 determined by the extent of the etch on the ejection side of the substrate. Control of the
10 lateral extent and shape of the recessed region **114** provides the ability to modify and control
11 the electric field pattern between the electrospray device **100** and an extracting electrode.

12 **Oxidation for electrical isolation**

13 As shown in the cross-sectional view of FIG. 15, a layer of silicon dioxide **221** is
14 grown on all silicon surfaces of the substrate **200** by subjecting the silicon substrate **200** to
15 elevated temperature in an oxidizing ambient. For example, the oxidizing ambient may be
16 an ultra-pure steam produced by oxidation of hydrogen for a silicon dioxide thickness greater
17 than approximately several hundred nanometers or pure oxygen for a silicon dioxide
18 thickness of approximately several hundred nanometers or less. The layer of silicon dioxide
19 **221** over all silicon surfaces of the substrate **200** electrically isolates a fluid in the channel
20 from the silicon substrate **200** and permits the application and sustenance of different
21 electrical potentials to the fluid in the channel **104** and to the silicon substrate **200**.

22 All silicon surfaces are oxidized to form silicon dioxide with a thickness that is
23 controllable through choice of temperature and time of oxidation. The final thickness of the
24 silicon dioxide can be selected to provide the desired degree of electrical isolation in the
25 device, where a thicker layer of silicon dioxide provides a greater resistance to electrical
26 breakdown.

27 **Metallization for electric field control**

28 FIGS. 16-20B illustrate the formation of a single conductive electrode electrically
29 connected to the substrate **200** on the ejection side **205** of the substrate **200**. As shown in the
30 cross-sectional view of FIG. 16, a film of positive-working photoresist **222** is deposited over
31 the silicon dioxide layer on the ejection side **205** of the substrate **200**. An area of the
32 photoresist **222** corresponding to the electrical contact area between the electrode and the
33 substrate **200** is selectively exposed through another mask by an optical lithographic

1 exposure tool passing short-wavelength light, such as blue or near-ultraviolet at wavelengths
2 of 365, 405, or 436 nanometers.

3 The photoresist **222** is then developed to remove the exposed area **224** of the
4 photoresist such that the electrical contact area between the electrode and the substrate **200**
5 is open to the underlying silicon dioxide layer **204** while the unexposed areas remain
6 protected by photoresist **222'**. The exposed area **224** of the silicon dioxide layer **204** is then
7 etched by a fluorine-based plasma with a high degree of anisotropy and selectivity to the
8 protective photoresist **222'** until the silicon substrate **200** is reached, as shown in the cross-
9 sectional view of FIG. 17.

10 Referring now to the cross-sectional view of FIG. 18, the remaining photoresist is
11 then removed in an oxygen plasma or in an actively oxidizing chemical bath like sulfuric
12 acid (H_2SO_4) activated with hydrogen peroxide (H_2O_2). Utilizing the patterned ejection side
13 silicon dioxide layer **204** as a mask, a high-dose implantation is made to form an implanted
14 region **225** to ensure a low-resistance electrical connection between the electrode and the
15 substrate **200**. A conductive film **226** such as aluminum may be uniformly deposited on the
16 ejection side **205** of the substrate **200** by thermal or electron-beam evaporation to form an
17 electrode **120**. The thickness of the conductive film **226** is preferably approximately 3000
18 Å, although shown having a larger thickness for clarity.

19 The conductive film **226** may be created by any method which does not produce a
20 continuous film of the conductive material on the side walls of the ejection nozzle **110**. Such
21 a continuous film would electrically connect the fluid in the channel **104** and the substrate
22 **200** so as to prevent the independent control of their respective electrical potentials. For
23 example, the conductive film may be deposited by thermal or electron-beam evaporation of
24 the conductive material, resulting in line-of-sight deposition on presented surfaces. Orienting
25 the substrate **200** such that the side walls of the ejection nozzle **110** are out of the line-of-
26 sight of the evaporation source ensures that no conductive material is deposited as a
continuous film on the side walls of the ejection nozzle **110**. Sputtering of conductive
material in a plasma is an example of a deposition technique which would result in
deposition of conductive material on all surfaces and thus is undesirable.

One or more additional conductive electrodes may be easily formed on the ejection
side **205** of the substrate **200**, as described above with reference to FIGS. 6 and 7. As shown
in the cross-sectional view of FIG. 19, a film of positive-working photoresist **228** is
deposited over the conductive film **226** on the ejection side **205** of the substrate **200**. Certain
areas of the photoresist **228** corresponding to the physical spaces between the electrodes are

1 selectively exposed through another mask by an optical lithographic exposure tool passing
2 short-wavelength light, such as blue or near-ultraviolet at wavelengths of 365, 405, or 436
nanometers.

3 Referring now to the plan and cross-sectional views of FIGS. 20A and 20B, the
4 photoresist **228** is developed to remove the exposed areas **230** of the photoresist such that the
5 exposed areas are open to the underlying conductive film **226** while the unexposed areas
6 remain protected by photoresist **228'**. The exposed areas **230** of the conductive film **226** are
7 then etched using either a wet chemical etch or a reactive-ion etch, as appropriate for the
8 particular conductive material. The etch is either selective to the underlying silicon dioxide
layer **204** or the etch must be terminated on the basis of etch rate and time of etch. Finally,
the remaining photoresist is then removed in an oxygen plasma.

9 The etching of the conductive film **226** to the underlying silicon dioxide layer **204**
10 results in physically and electrically separate islands of conductive material or electrodes.
11 As described above, these electrodes can be controlled independently from the silicon
12 substrate or channel fluid because they are electrically isolated from the substrate by the
13 silicon dioxide and from each other by physical separation. They can be used to further
14 modify the electric field line pattern and thereby effect a steering and/or shaping of the
electrosprayed fluid. This step completes the processing and fabrication sequence for the
electrospray device **100**.

15 As described above, the conductive electrode for application of an electrical
16 potential to the substrate of the electrospray device may be provided on the injection surface
17 rather than the ejection surface. The fabrication sequence is similar to that for the conductive
18 electrode provided on the ejection side **205** of the substrate **200**. FIGS. 20C-20G illustrate
19 the formation of a single conductive electrode electrically connected to the substrate **200** on
the injection side **203** of the substrate **200**.

20 As shown in the cross-sectional view of FIG. 20C, a film of positive-working
21 photoresist **232** is deposited over the silicon dioxide layer on the injection side **203** of the
22 substrate **200**. An area of the photoresist **232** corresponding to the electrical contact area
23 between the electrode and the substrate **200** is selectively exposed through another mask by
an optical lithographic exposure tool passing shortwavelength light, such as blue or near-
ultraviolet at wavelengths of 365, 405, or 436 nanometers.

24 The photoresist **232** is then developed to remove the exposed area **234** of the
25 photoresist such that the electrical contact area between the electrode and the substrate **200**
26 is open to the underlying Silicon dioxide layer **202** while the unexposed areas remain

1 protected by photoresist **232'**. The exposed area **234** of the silicon dioxide layer **202** is then
2 etched by a fluorine-based plasma with a high degree of anisotropy and selectivity to the
3 protective photoresist **232'** until the silicon substrate **200** is reached, as shown in the cross-
sectional view of FIG. 20D.

4 Referring now to the cross-sectional view of FIG. 20E, the remaining photoresist is
5 then removed in an oxygen plasma or in an actively oxidizing chemical bath like sulfuric
6 acid (H_2SO_4) activated with hydrogen peroxide (H_2O_2). Utilizing the patterned injection side
7 silicon dioxide layer **202** as a mask, a high-dose implantation is made to form an implanted
8 region **236** to ensure a low-resistance electrical connection between the electrode and the
9 substrate **200**. A conductive film **238** such as aluminum may be uniformly deposited on the
injection side **203** of the substrate **200** by thermal or electron beam evaporation to form an
electrode **120'**.

10 In contrast to the formation of the conductive electrode on the ejection surface of the
11 electrospray device, sputtering, in addition to thermal or electron-beam evaporation, may be
12 utilized to form the conductive electrode on the injection surface. Because the nozzle is on
13 the ejection rather than the injection side of the substrate, sputtering may be utilized to form
14 the electrode on the injection side as the injection side electrode layer does not extend to the
nozzle to create a physically continuous and thus electrically conductive path with the nozzle.

15 With the formation of the electrode on the injection surface of the electrospray
16 device, sputtering may be preferred over evaporation because of its greater ability to produce
17 conformal coatings on the sidewalls of the exposed area **234** etched through the silicon
dioxide layer **202** to the substrate **200** to ensure electrical continuity and reliable electrical
contact to the substrate **200**.

18 For certain applications, it may be necessary to ensure electrical isolation between
19 the substrate **200** and the fluid in the electrospray device by removing the conductive film
20 from the region of the surface adjacent to the entrance orifice **106** on the injection side **203**.
21 The extent of the conductive film **238** which should be removed is irrespective of etching
22 method and may be determined by the specific method utilized in creating the interface
23 between the upstream fluid delivery system/sub-system and the injection side of the
electrospray device. For example, a diameter of between approximately 0.2-2 mm of the
conductive film **238** may be removed from the region surrounding the entrance orifice **106**.

24 As shown in the cross-sectional view of FIG. 20F, another film of positive-working
25 photoresist **240** is deposited over the conductive film **238** on the injection side **203** of the
26 substrate **200**. An area of the photoresist **240** corresponding to the region adjacent to the

1 entrance orifice **106** on the injection side **203** is selectively exposed through another mask
2 by an optical lithographic exposure tool passing short-wavelength light, such as blue or near-
ultraviolet at wavelengths of 365, 405, or 436 nanometers.

3 The photoresist **240** is then developed to remove the exposed area **242** of the
4 photoresist such that the region adjacent to the entrance orifice **106** on the injection side **203**
5 is open to the underlying conductive film **238** while the unexposed areas remain protected
6 by photoresist **240'**. The exposed area **242** of the conductive film **238** is then etched by, for
7 example, a chlorine-based plasma with a high degree of anisotropy and selectivity to the
8 protective photoresist **240'** until the silicon dioxide layer **203** is reached, as shown in the
cross-sectional view of FIG. 20G.

9 The specific technique for etching the conductive film **238** may be determined by
10 the specific conductive material deposited. For example, aluminum may be etched either in
11 a wet chemical bath using standard aluminum etchant or in a plasma using reactive-ion
12 etching (RIE) and chlorine-based gas chemistry. Utilization of standard wet aluminum
13 etchant to etch an aluminum film may be preferred as such wet etching may facilitate the
14 removal of any undesired conductive material deposited in the channel **104** via the entrance
orifice **106**. Further, although chlorine-based reactive-ion etching may be utilized, such
etching may lead to aluminum corrosion if removal of the photoresist is delayed.

15 Forming the electrode on the injection surface for application of an electric potential
16 to the substrate of the electrospray device may provide several advantages. For example,
17 because the ability to uniformly coat photoresist on a surface is limited by nonplanar surface
18 topology, coating photoresist on the much flatter injection side results in a more uniform and
19 continuous photoresist film than coating photoresist on the ejection side. The uniformity and
20 continuity of the photoresist film directly and positively impact the reliability and yield, at
least in part because failure of photoresist coverage would allow subsequent etching of
silicon dioxide in undesired locations during the etching of exposed areas **224**, **234**.

21 Another advantage of forming the electrode on the injection surface is the greater
22 flexibility and reliability in the conductive material deposition step because the interior
23 surfaces of the nozzle are not coated by the conductive material deposited onto the injection
24 surface rather than onto the ejection surface of the electrospray device. As a result,
25 sputtering may be utilized as a deposition technique to ensure conformal coating of the
26 conductive material and electrical continuity from the surface to the substrate contact.
Further, the provision of the electrode on the injection surface does not preclude the
deposition and patterning of additional conductive electrodes on the ejection side to further

1 modify the electric field line pattern to effect, for example, a steering and/or shaping of the
2 electrospray, as such additional electrodes do not required electrical contact to the substrate.

3 The ability to form the electrode on the injection surface may also be advantageous
4 in certain applications where physical constraints, such as in packaging, may dictate the need
5 for injection-side rather than ejection-side electrical connection.

6 The above described fabrication sequence for the electrospray device **100** can be
7 easily adapted to and is applicable for the simultaneous fabrication of a single monolithic
8 system comprising multiple electrospray devices including multiple channels and/or multiple
9 ejection nozzles embodied in a single monolithic substrate. Further, the processing steps
10 may be modified to fabricate similar or different electrospray devices merely by, for example,
11 modifying the layout design and/or by changing the polarity of the photomask and utilizing
12 negative-working photoresist rather than utilizing positive-working photoresist.

13 Further, although the fabrication sequence is described in terms of fabricating a
14 single electrospray device, the fabrication sequence facilitates and allows for massively
15 parallel processing of similar devices. The multiple electrospray devices or systems
16 fabricated by massively parallel processing on a single wafer may then be cut or otherwise
17 separated into multiple devices or systems.

18 **INTERFACE OR INTEGRATION OF THE ELECTROSPRAY DEVICE**

19 **Downstream Interface or Integration of the Electrospray Device**

20 The electrospray device **100** may be interfaced or integrated downstream to a
21 sampling device, depending on the particular application. For example. the analyte may be
22 electrosprayed onto a surface to coat that surface or into another device for purposes of
23 conveyance, analysis, and/or synthesis. As described above with reference to FIG. 5, highly
24 charged droplets are formed at atmospheric pressure by the electrospray device **100** from
25 nanoliter-scale volumes of an analyte. The highly charged droplets produce gas-phase ions
26 upon sufficient evaporation of solvent molecules which may be sampled, for example,
through an orifice of an atmospheric pressure ionization mass spectrometer (API-MS) for
analysis of the electrosprayed fluid.

27 **Upstream Interface or Integration of the Electrospray Device**

28 Referring now to FIGS. 21-23, fluid may be delivered to the entrance orifice of the
29 electrospray device in any suitable manner by upstream interface or integration with one or
30 more fluid delivery devices, such as piezoelectric pipettes, micropipettes, capillaries and
31 other types of microdevices. The fluid delivery device may be a separate component to form
32 a heterogeneous interface with the entrance orifice of the electrospray device. Alternatively,

1 the fluid delivery device may be integrated with the electrospray device to form a
2 homogeneous interface with the entrance orifice of the electrospray device.

3 FIGS. 21A and 21B illustrate examples of fluid delivery devices forming
4 heterogeneous interfaces with the entrance orifice of the electrospray device. Preferably, the
5 heterogeneous interface is a non-contacting interface where the fluid delivery device
6 and the electrospray device are physically separated and do not contact. For example, as
7 shown in the cross-sectional view of FIG. 21A, a piezoelectric pipette **300** is positioned at
8 a distance above the injection surface **108** of the electrospray device **100A**. The piezoelectric
9 pipette **300** deposits a flow of microdroplets, each approximately 200 pL in volume, into the
10 channel **104** through the entrance orifice **106A**. Preferably, the electrospray device **100A**
11 provides an entrance well **302** at the entrance orifice **106A** for containing the sample fluid
12 prior to entering the channel **104** particularly when it is desirable to spray a volume of fluid
13 greater than the volume of the through-substrate channel **104** and continual supply of fluid
14 is not feasible such as when using the piezoelectric pipette **300**. The entrance well **302**
15 preferably has a volume of 0.1 nL to 100 nL. Furthermore, to apply an electric potential to
16 the fluid, an entrance well electrode **304** may be provided on a surface of the entrance well
17 **302** parallel to the injection surface **108**. Alternatively, a wire (not shown) may be
18 positioned in channel **104** via the entrance orifice **106A**. Preferably, some fluid is present
19 in the entrance well **302** to ensure electrical contact between the fluid and the entrance well
20 electrode **304**.

21 Alternatively, the heterogeneous interface may be a contacting interface where a
22 fluid delivery device is attached by any suitable method, such as by epoxy bonding, to the
23 electrospray device to form a continuous sealed flow path between the upstream fluid source
24 and the channel of the electrospray device. For example, FIG. 21B shows a cross-sectional
25 view of a capillary **306** prior to attachment to the entrance orifice **106** of the electrospray
26 device **100B**. The injection surface **108** of the electrospray device **100B** may be adapted to
facilitate attachment of the capillary **306**. Such features can be easily designed into the mask
for the injection side of the substrate and can be simultaneously formed with the injection
side portion of the channel during the etching performed on the injection-side.

For example, where the inner diameter of the capillary **306** is greater than that of the
channel **104** and the entrance orifice **106**, the electrospray device **100B** preferably defines a
region **308** recessed from the injection surface **108** to form a mating collar for mating and
affixing with the capillary **306**. Thus, capillary **306** may be positioned and attached in the
recessed region **308** such that the exit orifice **310** portion of the capillary **302** is positioned

1 around the entrance orifice **106**. Further, the electrospray device **100B** may optionally
2 provide an entrance well **312** at the entrance orifice **106B** for containing the sample fluid
3 prior to entering the channel **104**. Although not shown, if the outer diameter of the capillary
4 is less than that of the channel and the entrance orifice, the capillary may be inserted into and
attached to the entrance orifice of the electrospray device.

5 Referring now to the schematic of FIG. 22, rather than a heterogeneous interface,
6 a single integrated system **316** is provided wherein an upstream fluid delivery device **318**
7 forms a homogeneous interface with the entrance orifice (not shown) of an electrospray
8 device **100**. The system **316** allows for the fluid exiting the upstream fluid delivery device
9 **318** to be delivered on-chip to the entrance orifice of the electrospray device **100** in order to
generate an electrospray.

10 The single integrated system **316** provides the advantage of minimizing or
11 eliminating extra fluid volume to reduce the risk of undesired fluid changes, such as by
12 reactions and/or mixing. The single integrated system **316** also provides the advantage of
13 eliminating the need for unreliable handling and attachment of components at the
microscopic level and of minimizing or eliminating fluid leakage by containing the fluid
within one integrated system.

14 The upstream fluid delivery device **318** may be a monolithic integrated circuit
15 having an exit orifice through which a fluid sample can pass directly or indirectly to the
entrance orifice of the electrospray device **100**. The upstream fluid delivery device **318** may
16 be a silicon microchip-based liquid separation device capable of, for example, capillary
17 electrophoresis, capillary electrochromatography, affinity chromatography, liquid
chromatography (LC) or any other condensed-phase separation methods. Further, the
18 upstream fluid delivery device **318** may be a silicon, glass, plastic and/or polymer based
19 device such that the electrospray device **100** may be chip-to-chip or wafer-to-wafer bonded
20 thereto by any suitable method. An example of a monolithic liquid chromatography device
for utilization in, for example, the single integrated system **316**, is described below.

21 **Electrospray Device for Sample Transfer of Combinatorial Chemistry**
22 **Libraries Synthesized in Microdevices**

23 The electrospray device may also serve to reproducibly distribute and deposit a
24 sample from a mother plate to daughter plate(s) by nanoelectrospray deposition. Electrospray
device(s) may be etched into a microdevice capable of synthesizing combinatorial chemical
25 libraries. At the desired time, the nozzle may spray a desired amount of the sample from the
26 mother plate to the daughter plate(s). Control of the nozzle dimensions, applied voltages,

1 and time of spraying may provide a precise and reproducible method of sample deposition
2 from an array of nozzles, such as the generation of sample plates for molecular weight
3 determinations by matrix-assisted laser desorption/ionization time-of-flight mass
4 spectrometry (MALDI-TOFMS). The capability of transferring analytes from a mother plate
5 to daughter plates may also be utilized to make other daughter plates for other types of
6 assays, such as proteomic screening.

7 FIGS. 23A and 23B show; respectively, an exploded perspective view and a cross-
8 sectional view along line 23B-23B, of a chip-based combinatorial chemistry system **320**
9 comprising a reaction well block or titer plate **322** and a receiving or daughter plate **324**. The
10 reaction well block **322** defines an array of reservoirs **326** for containing the reaction
11 products from a combinatorially synthesized compound. The reaction well block **322** further
12 defines channels **328**, nozzles **330** and recessed portions **332** such that the fluid in each
13 reservoir **326** may flow through a corresponding channel **328** and exit through a
14 corresponding nozzle **330** in the form of an electrospray. The reaction well block **322** may
15 define any number of reservoir(s) in any desirable configuration, each reservoir being of a
16 suitable dimension and shape. The volume of a reservoir **326** may range from a few
17 nanoliters up to several microliters and more preferably ranges between approximately 200
18 nL to 1 μ L.

19 The reaction well block **322** may serve as a mother plate to interface to a microchip-
20 based chemical synthesis apparatus such that the electrospray function of the reaction well
21 block **322** may be utilized to reproducibly distribute discreet quantities of the product
22 solutions to a receiving or daughter plate **324**. The daughter plate **324** defines receiving
23 wells **334** which correspond to each of the reservoirs **326**. The distributed product solutions
24 in the daughter plate **324** may then be utilized to screen the combinatorial chemical library
25 against biological targets.

26 **Illustration of an Electrospray Device Generating an Electrospray Spray**

FIGS. 24A and 24B show color images of a real Taylor cone emanating from an
integrated silicon chip-based nozzle. FIGS. 24C and 24D are perspective and side cross-
sectional views, respectively, of the electrospray device and mass spectrometer system shown
in FIGS. 24A and 24B. FIGS. 24A shows a chip-integrated electrospray device comprising
a nozzle and a recessed portion or annulus, and a Taylor cone, liquid jet and plume of highly-
charged electrosprayed droplets of methanol containing 10 μ g/mL polypropylene glycol 425
(PPG425) containing 0.2% formic acid. FIG. 24B shows an ion-sampling orifice of a mass
spectrometer in addition to the electrospray device.

1 The electrospray device **100** is interfaced upstream with a pipette **52'**. As shown in
2 the upper right corner of each of FIGS. 24A and 24B and in FIGS. 24C and 24D, the tip of
3 the pipette **52'** is press-sealed to the injection side of the electrospray device **100**. The
4 electrospray device **100** has a 10 μm diameter entrance orifice on the injection side, a 30 μm
5 inner diameter and a 60 μm outer diameter nozzle, a 15 μm nozzle wall thickness and a 150
6 μm nozzle depth. The recessed portion or the annulus extends 300 μm from the outer
7 diameter of the nozzle. The voltage applied to the fluid V_{fluid} introduced to the electrospray
8 device and thus the nozzle voltage is 900 V. The voltage applied to the substrate $V_{\text{substrate}}$ and
9 thus the electrospray device is 0 V. The voltage applied to the mass spectrometer which also
10 serves as an extracting electrode V_{extract} is approximately 40 V. The liquid sample was
11 pumped using a syringe pump at a flow of 333 nL/min through the pipette tip pressed-sealed
12 against the injection side of the electrospray device. The nozzle is approximately 5 mm from
13 the ion-sampling orifice **62** of the mass spectrometer **60**. The ion-sampling orifice **62** of the
14 mass spectrometer **60** generally defines the acceptance region of the mass spectrometer **60**.
15 The mass spectrometer for acquiring the data was the LCT Time-Of-Flight mass
16 spectrometer of Micromass, Inc.

17 FIG. 24E shows a mass spectrum of 1 $\mu\text{g/mL}$ PPG425 in 50% water, 50% methanol
18 containing 0.1% formic acid, 0.1% acetonitrile and 2 mM ammonium acetate. The data were
19 collected at a flow rate of 333 nL/min.

20 LIQUID CHROMATOGRAPHY DEVICE

21 In another aspect of the invention shown in the exploded perspective and cross-
22 sectional views of FIGS. 25A and 25B, respectively, a silicon-based liquid chromatography
23 device **400** generally comprises a silicon substrate or microchip **402** defining an introduction
24 channel **404** through the substrate **402** extending between an entrance orifice **406** on a first
25 surface **408** and a fluid reservoir **410**, a separation channel **412** extending between the
26 reservoir **410** and an exit orifice **414**, a plurality of separation posts **416** along the separation
channel **412**, and a cover **420** to provide an enclosure surface adjacent the cover **420** for the
reservoir **410** and the separation channel **412** adjacent the cover **420**.

The plurality of separation posts **416** extends from a side wall of the separation
channel **412** in a direction perpendicular to the fluid flow through the separation channel **412**.
Preferably, one of the ends of each separation post **416** does not extend beyond and is
preferably coplanar or level with the second surface **417**. The separation channel **412** is
functionally similar to the liquid chromatography column in that component separation
occurs in the separation channel **412** where the plurality of separation posts **416** perform the

1 liquid chromatography function. Component separation occurs through the interaction of the
2 fluid flowing through the separation channel **412** wherein the columnar separation posts **416**
3 provides the large surface area. The surfaces of the separation channel **412** and the
4 separation posts **416** are preferably provided with an insulating layer to insulate the fluid in
5 the separation channel **412** from the substrate **402**. Specifically, the separation posts **416** are
6 preferably oxidized silicon posts which may be chemically modified using known techniques
7 in order to optimize the interaction of the components of the sample fluid with the stationary
8 phase, the separation posts **416**. In one embodiment, the separation channel **412** extends
beyond the separation posts **416** to the edge of the substrate **402** and terminating as the exit
orifice **414**.

9 The introduction channel, **404**, the separation channel **412**, the reservoir **410** and the
10 separation posts **416** may have any suitable cross-sectional shapes such as circular and/or
11 rectangular. Preferably, the separation posts **416** have the same cross-sectional shapes and
sizes but may nonetheless have different cross-sectional shapes and/or sizes.

12 The liquid chromatography device **400** further comprises a layer of silicon dioxide
13 **422** over the surfaces of the substrate of the cover **420** and a layer of silicon dioxide **424** over
14 the surfaces of the substrate **402**. The silicon dioxide layers **422**, **424** electrically isolate a
15 fluid contained in the reservoir **410** and the separation channel **412** from the substrate **402**
16 and the substrate of the cover **420**. The silicon dioxide layers **422**, **424** are also relatively
inactive and thus less likely to interact with fluids in the reservoir **410** and the separation
channel **412** than bare silicon.

17 Depending on the specific application, the substrate **402** may provide a surface on
18 which one or more conductive electrodes in electrical contact with the fluid in the device **400**
19 may be formed. For example, a reservoir electrode **426** and/or an exit electrode **428** may be
20 provided on the second surface **417** of the substrate **402** such that a corresponding electrode
21 would be in electrical contact with fluid in the reservoir **410** and near the exit orifice **414**,
22 respectively. A filling electrode **430** may also be provided on the second surface **417** of the
23 substrate **402** such that it would be in electrical contact with fluid in the unpopulated portion
24 **432** of the separation channel **412** between the reservoir **410** and the first occurrence of
25 separation posts **416**. The shape, size and location along the fluidic flow path of each
26 electrode on the substrate **402** may be determined by design considerations such as the
distance between adjacent electrodes. Further, any or all of the electrodes may be
alternatively or additionally formed on the bonding surface **425** of the cover **420**. For
example, the filling electrode **430** may be alternatively positioned such that it would be in

1 electrical contact with fluid in the separation channel **412** adjacent the reservoir **410**.
2 Further, additional electrodes may be provided, for example, to create an arbitrary electrical
3 potential distribution along the fluidic flow path.

4 Providing two or more of the reservoir, filling and exit electrodes along with
5 electrical isolation of the fluid sample in the device **400** from the substrate **402** and the
6 substrate of the cover **420** allows for the application and sustenance of different (or same)
7 electric potentials at two or more different locations along the fluidic path. The difference
8 in electric potentials at two or more different locations along the fluidic path causes fluidic
9 motion to occur between the two or more locations. Thus, these electrodes may facilitate the
10 filling of the reservoir **410** and/or the driving of the fluid through the separation channel **412**.

11 Further, through appropriate layout design and fabrication processes, the substrate
12 **402** and/or the cover **420** may also provide additional functionalities such as pre-conditioning
13 of the fluid prior to delivery into the reservoir **410**, and/or conveying, analyzing, and/or
14 otherwise treating fluidic samples exiting from the separation channel **412**. The cover **420**
15 may provide such additional functionality on either or both surfaces and/or the bulk of the
16 cover **420**.

17 The cover **420** may comprise a substrate **418** comprising silicon or any other suitable
18 material, such as glass, plastics and/or polymers. The specific material for the cover **420** may
19 depend upon, for example, whether direct observation of a fluoresced fluid is desired such
20 that glass may be more desirable and/or the consideration of the ease of fabrication of the
21 cover **420** by utilizing similar processing techniques as for the substrate **402** such that silicon
22 may be more desirable. The cover **420** may be bonded or otherwise affixed to form a
23 hermetic seal between the substrate **402** and the cover **420** in order to ensure the appropriate
24 level of fluid containment and isolation. For example, several methods of bonding silicon
25 to silicon or glass to silicon are known in the art, including anodic bonding, sodium silicate
26 bonding, eutectic bonding, and fusion bonding. The specific hermetic bonding method may
depend on various factors such as the physical form of the surfaces of the substrate **402** and
the cover **420** and/or the application and functionality of the integrated system and/or the
liquid chromatography device **400**.

Dimensions of the liquid chromatography device **400** may be determined according
to various factors such as the specific application, the layout design as well as the device with
which it is to be interfaced or integrated. The surface dimensions, i.e. the dimensions in the
X and Y directions, of the elements of the liquid chromatography device **400** may be
determined by layout design and through the corresponding photomasks used in fabrication.

1 The depth or height, i.e. the dimension in the Z direction, of the elements of the liquid
2 chromatography device **400** may be determined by the etch processes during fabrication, as
3 described below. The depth or height of the elements is independent of the surface
4 dimensions to a first-order approximation although the aspect ratio limitations of the
5 reactive-ion etch places constraints on the etch depth, particularly with the small surface
6 openings in the channel **412** between the separation posts **416**.

7 Further, the size, number, cross-sectional shape, spacing and placement of the
8 separation posts **416** may also be determined by layout design to achieve the desired flow
9 rate and to prevent low-resistance lines of sight within the separation channel **412** to ensure
10 adequate fluid-surface interaction. Each separation post **416** may have the same or different
11 characteristics such as size and/or cross-sectional shape. The cross-sectional shape of the
12 posts may be chosen in layout design to optimize fluid/boundary layer interactions at the post
13 surfaces. The separation posts **416** may be placed in any desired pattern in the separation
14 channel **412**, such as periodic, semi-periodic, or random. Close spacing of the separation
15 posts **416** may be desirable for maximization of the surface interactions with the fluid.
16 Similarly, minimizing the cross-sectional area of the separation posts **416** may permit
17 placement of greater number in the separation channel **412**. However, the reduction of the
18 cross-sectional area of the separation posts **416** is limited by the resulting reduction in the
19 mechanical stability necessary during processing.

20 Control of the size, number, cross-sectional shape, spacing and placement of the
21 separation posts **416** provides advantages over traditional liquid chromatography as the
22 traditional separation column packing materials have undesired dispersion in size distribution
23 as well as random spacing variations.

24 In one currently preferred embodiment, the substrate **402** of the liquid
25 chromatography device **400** is approximately 250-600 μm in thickness, the separation
26 channel **412** has a depth of approximately 10 μm , the rectangular reservoir **410** is
approximately 1000 μm by 1000 μm resulting in a volume of approximately 10 nL. The
depth of the reservoir **410** and the separation channel **412** is limited by the height of the
separation posts **416** which is in turn limited by the maximum etch aspect ratio. The nearest-
neighbor spacing of the separation posts **416** is preferably less than approximately 5 μm .
The dimensions of the reservoir **410** determine the volume of the fluid sample which can be
used for the liquid chromatography separation and, as is evident, through the independent
control of surface dimensions and the depth, the reservoir **410** may be designed to have any
desired volume. Preferably, the diameter of the entrance orifice **406** is 100 μm or less such

1 that the fluid surface tension would be sufficient to maintain the fluid in the reservoir **410**
2 to prevent leakage therefrom.

3 The silicon-based liquid chromatography device **400** reduces the size of a typical
4 liquid chromatography device by nearly two orders of magnitude. The dimensional scaling
5 may provide the advantage of significantly reducing the mass of the analyte and/or the
6 volume of the fluid sample required for accurate analysis. Further, by reducing a
macroscopic separation column and its packing materials to a monolithic device, the liquid
chromatography device **400** can be a component of an on-chip integrated system.

7 Further, all features such as the reservoir, the separation channel and the separation
8 posts are recessed from the substrate **402**. The portion of the substrate **402** exterior to the
9 reservoir and the separation channel thus serves to physically protect the separation posts
10 from casual abrasion and stress fracture in handling and subsequent bonding of the substrate
11 **402** and the cover **420**. Because the posts are integral with the substrate, the posts are
12 inherently stable and thus allow for the use of a pressurized system without the risk of
damage to the stationary phase which may otherwise result with the use of conventional
packing materials in conventional high-performance liquid chromatography systems.

13 An upstream fluid delivery system, such as a micropipette, piezoelectric pipette or
14 small capillary, may be press-sealed onto the exterior surface of the liquid chromatography
15 device **400** such that the pipette or capillary is concentric with the entrance orifice **406**.
16 Optionally, the liquid chromatography device may provide a collar (not shown) to facilitate
17 the mating and affixing of the fluid delivery device to the liquid chromatography device
similar to the mating collar of the electrospray device as discussed with reference to FIG.
21B.

18 To operate the liquid chromatography device **400**, the fluid reservoir **410** may first
19 be filled with a sample fluid by injecting the fluid from a fluid delivery device through the
20 introduction channel **404** via the entrance orifice **406**. Any suitable fluid delivery device
21 such as a micropipette, a piezoelectric pipette or a small capillary may be utilized. The
22 volume of the sample fluid injected into the liquid chromatography device **400** may be up
23 to approximately the volume of the reservoir **410** plus a relatively small volume remaining
in the introduction channel **404**.

24 The filling of the reservoir **410** may be facilitated by applying an appropriate
25 potential voltage difference between the reservoir electrode **426** and the filling electrode **430**,
26 such as approximately 1000 V/cm of introduction channel **404**. In particular, a volume of
the fluid is first introduced into the reservoir **410** through the introduction channel **404** via

1 the entrance orifice **406** to coat or prime the surfaces of the reservoir **410** and the
2 introduction channel **404** by capillary action to allow for electrical contact between the fluid
3 and the reservoir and filling electrodes **426**, **430**. Where the filling electrode **430** is
4 positioned in a portion of the separation channel **412** unpopulated by separation posts **416**,
5 the filling electrode **430** also facilitates the filling of the portion of the channel **412** between
6 the reservoir **410** and the filling electrode **430**.

7 After filling the reservoir **410** with an appropriate volume of the sample fluid, any
8 suitable method may then be utilized to drive the fluid from the reservoir **410** into the
9 separation channel **412**. For example, the fluid may be driven from the filled reservoir **410**
10 through the separation channel **412** by applying hydrostatic pressure to the reservoir **410** via
11 the entrance orifice **406**.

12 Alternatively or additionally, the fluid may be driven through the separation channel
13 **412** by applying a suitable electrokinetic potential voltage difference between the reservoir
14 electrode **426** and the exit electrode **428** to generate electrophoretic or electroosmotic fluidic
15 motion. Preferably, the electric potential difference is approximately 1000 V/cm of
16 separation channel length. Of course, any other suitable methods of inducing fluidic motion
17 may be utilized. Pressure-driven and voltage-driven flow effect different separation
18 efficiencies. Thus, depending upon the application, one or both may be utilized.

19 Fluid then exits from the separation channel **412** through the exit orifice **414** to, for
20 example, a capillary **434**, which has an off-chip interconnection with the exit orifice **414**, as
21 shown in FIG. 26. Alternatively, as shown in FIG. 27, the liquid chromatography device **400**
22 may perform separation on the fluid from reservoir **410** such that selected analytes from the
23 separation performed by posts **416** passes through unpopulated channel **436** to another on-
24 chip device **438**, such as for analysis and/or mixing, while the remainder of the fluid is
25 directed to the waste reservoir **439**. The unpopulated channel **436** may be a mere
26 continuation of the separation channel **412** of the liquid chromatography device **400** or a
channel separate from the separation channel **412**.

Two or more fluid samples may be driven through the liquid chromatography device
400 by successively filling the reservoir and driving the fluid through the separation channel
412. For example, in certain applications, it may be desirable or necessary to first coat the
surfaces of the separation posts **416** with one or more reagents and then pass an analyte
sample over the conditioned separation posts **416**.

Various modifications may be made to the liquid chromatography device describe
above. For example, as shown in FIG. 28, rather than defining the entrance orifice and the

1 introduction channel in the substrate, the liquid chromatography device **400'** may provide
2 an introduction channel **404'** in the cover **420'** such that the entrance orifice **406'** is defined
3 on an exterior surface of the cover **420'**. Further, the cover **420'** may define an exit channel
4 **413** between an exit orifice **414'** defined on an exterior surface of the cover **420'** and a
separation channel **412'** which terminates within the substrate **402'**.

5 In another variation, an additional introduction channel **440** and entrance orifice **442**
6 may be defined in the substrate **402''**, as shown in FIG. 29, or in the cover (not shown). The
7 additional introduction channel **440** introduces fluid to the separation channel **412''** such that
8 the fluid from the additional introduction channel **440** intersects the path of fluid flow from
9 the reservoir **410** through the unpopulated portion **432''** of the separation channel **412''**. The
10 fluid reservoir **410** may be utilized as a buffer for an eluent and the additional introduction
11 channel **440** may be utilized to introduce the fluid sample to the separation channel **412''**.
12 Further, the additional entrance orifice **442** may be utilized to introduce several fluid samples
13 in succession into the separation channel **412''**. For example, in certain applications, it may
14 be necessary to first coat the surfaces of the separation posts **416** with one reagent and then
15 pass an analyte over the conditioned surfaces of the separation posts **416**.

16 Referring now to FIGS. 30-35, although the liquid chromatography device has been
17 described as comprising a single reservoir and a single separation channel, the monolithic
18 liquid chromatography device may be easily adapted and modified to comprise multiples of
19 the liquid chromatography device and/or multiple entrance orifices, exit orifices, reservoirs
20 and/or separation channels. In each of the variations, any or all of the reservoir(s), separation
21 channel(s), and separation posts may have different dimensions and/or shapes.

22 For example, multiple reservoir-separation channel combinations may be provided
23 on a single chip. In particular, as shown in FIG. 30, a reservoir **410A** may feed into a
24 separation channel **412A** having separation posts **416A** and another reservoir **410B** may feed
25 into another separation channel **412B** having separation posts **416B**.

26 In another variation as shown in FIG. 31, a single reservoir **410C** may feed multiple
separation channels **412C**, **412D**. Each of separation channels **412C**, **412D** may have therein
separation posts **416C**, **416D**, respectively, which may have the same or different properties,
such as number, size and shape. Another channel **412E** may be provided as a null channel
completely unpopulated by separation posts. The output from the null channel **412E** may
be utilized as a basis of comparison to the output from the separation channel(s) populated
by separation posts. Alternatively, all of the channels **412C**, **412D**, **412E** may be separation
channels having separation posts.

1 Referring now to FIG. 32, fluid from multiple reservoirs **410E** and **410F** may feed
2 into a single separation channel **412F** via connecting channels **444E**, **444F**, respectively. The
3 connecting channels **444E**, **444F** are preferably unpopulated by separation posts to facilitate
4 the mixing of the fluid samples from the reservoirs **410E**, **410F** prior to passage through the
5 separation channel **412F**. The mixing of samples may be utilized to condition the primary
6 sample of interest prior to separation or to effect a reaction between the samples prior to
7 passage through the populated portion of the separation channel **412F**. Alternatively, fluid
8 such as a conditioning fluid from one reservoir **410E** may flow through the separation
9 channel **412F** in order to condition the surfaces of the separation posts **416F** prior to the
10 passage of the other sample such as an analyte sample from the other reservoir **410F**.
11 Although the separation posts **416F** are shown as having different cross-sections, separation
12 posts **416F** may have the same size and cross-sectional shape.

13 Alternatively, in addition to having fluid from multiple reservoirs feed into a single
14 separation channel via connecting channels, fluid from another reservoir may be introduced
15 to the fluid flow along the separation channel, before and/or after the fluid has passed
16 through the populated portion of the separation channel. For example, FIG. 33 shows that
17 the fluid from multiple reservoirs **410G**, **410H** may be fed into a single separation channel
18 **412G** via connecting channels **444G**, **444H**, respectively, and fluid from another reservoir
19 **410I** may be introduced to the fluid flow along the separation channel **412G** after the fluid
20 has passed the separation posts **416G**. FIG. 34 shows that the fluid from multiple reservoirs
21 **410J**, **410K** may be fed into a single separation channel **412J** via connecting channels **444J**,
22 **444K**, respectively, and fluid from another reservoir **410L** may be introduced to the fluid
23 flow along the separation channel **412J** prior to the fluid passing the separation posts **416J**.

24 For devices having multiple reservoirs and/or multiple channels, separate electrodes
25 may be provided for each reservoir and/or for each channel, for example, in the unpopulated
26 portion of the channel upstream from the separation posts and/or near the exit of the channel.
Such provision of separate electrodes allow for the separate and independent control of the
fluidic flow for filling each reservoir and/or for driving the fluid through the separation
channel.

The electric control may be simplified by having one common reservoir electrode,
one common filling electrode, and/or one exit electrode among the multiple reservoirs and/or
multiple channels. For example, each of the multiple reservoirs may be separately filled by
applying a first voltage to the common reservoir electrode and a second voltage, different
from the first voltage, to the filling electrode corresponding to the reservoir to be filled while

In yet another variation shown in FIG. 35, in addition to a sample reservoir **410M** and separation posts **416M**, a plurality of posts **416L** may be provided in a channel **412M** upstream from the separation posts **416M** for providing additional functionality such as solid-phase extraction (SPE) for sample pretreatment. The SPE posts **416L** may be the same, similar to or different from the separation posts **416M** simply by varying the layout design. The SPE posts **416L** may provide surface functionality different from that of the separation posts **416M**. Alternatively, rather than providing a sample reservoir, an introduction channel (not shown) may be utilized to introduce a fluidic sample directly in the channel **412M** by allowing direct injection of the sample therein. Further, reservoirs **410N**, **410P** may be provided to contain fluidic buffers necessary for sample pretreatment upstream of the posts **416L**. For example, an eluent reservoir may be provided for eluting analytes and a wash reservoir may be provided for sample cleanup.

- Page 39 -

LIQUID CHROMATOGRAPHY DEVICE FABRICATION PROCEDURE

The fabrication of the liquid chromatography device of the present invention will now be explained with reference to FIGS. 36A-46B. The liquid chromatography device is preferably fabricated as a monolithic silicon micro device utilizing established, well-controlled thin-film silicon processing techniques such as thermal oxidation, photolithography, reactive-ion etching (RIE), ion implantation, and metal deposition. Fabrication using such silicon processing techniques facilitates massively parallel processing of similar devices, is time- and cost-efficient, allows for tighter control of critical dimensions, is easily reproducible, and results in a wholly integral device, thereby eliminating any assembly requirements. Manipulation of separate components and/or sub-assemblies to build an liquid chromatography device with high reliability and yield is not desirable and may not be possible at the micrometer dimensions required for efficient separation.

Further, the fabrication sequence may be easily extended to create physical aspects or features to facilitate interfacing, integration and/or connection with devices having other functionalities or to facilitate integration with a fluid delivery subsystem to create a single integrated system. Consequently, the liquid chromatography device may be fabricated and utilized as a disposable device, thereby eliminating the need for column regeneration and eliminating the risks of sample cross-contamination.

Referring to the plan and cross-sectional views, respectively, of FIGS. 36A and 36B, a silicon wafer separation substrate **500**, double-side polished and approximately 250-600 μm in thickness, is subjected to an elevated temperature in an oxidizing ambient to grow a layer or film of silicon dioxide **502** on the reservoir side **503** and a layer or film of silicon dioxide **504** on the back side **505** of the separation substrate **500**. Each of the resulting silicon dioxide layers **502**, **504** has a thickness of approximately 1-2 μm . The silicon dioxide layers **502**, **504** provide electrical isolation and also serve as masks for subsequent selective etching of certain areas of the separation substrate **500**.

A film of positive-working photoresist **506** is deposited on the silicon dioxide layer **502** on the reservoir side **503** of the separation substrate **500**. Certain areas of the photoresist **506** corresponding to the reservoir, separation channel and separation posts which will be subsequently etched are selectively exposed through a mask by an optical lithographic exposure tool passing short-wavelength light, such as blue or near-ultraviolet at wavelengths of 365, 405, or 436 nanometers.

1 Referring to the plan and cross-sectional views, respectively, of FIGS. 37A and 37B,
2 after development of the photoresist **506**, the exposed areas **508, 509, 510** of the photoresist
3 corresponding to the reservoir, separation posts and channel, respectively, are removed and
4 open to the underlying silicon dioxide layer **502** while the unexposed areas remain protected
5 by photoresist **506'**. The exposed areas **508, 509, 510** of the silicon dioxide layer **502** are
6 then etched by a fluorine-based plasma with a high degree of anisotropy and selectivity to
7 the protective photoresist **506'** until the silicon separation substrate **500** is reached. The
8 remaining photoresist is removed in an oxygen plasma or in an actively oxidizing chemical
9 bath like sulfuric acid (H_2SO_4) activated with hydrogen peroxide (H_2O_2).

10 As shown in the cross-sectional view of FIG. 38, the reservoir **410**, the separation
11 channel **412**, and the separation posts **416** in the separation channel **412** are vertically formed
12 in the silicon separation substrate **500** by another fluorine-based etch. Preferably, the
13 reservoir **410** and the separation channel **412** have the same depth controlled by the etch time
14 at a known etch rate. The simultaneous formation of the reservoir **410** and the channel **412**
15 ensures uniform depth such that there are no discontinuities in the fluid-constraining surfaces
16 to impede the fluid flow. The depth of the reservoir **410** and the channel **412** is preferably
17 between approximately 5-20 μm and more preferably approximately 10 μm . The etch can
18 reliably and reproducibly be executed to produce an aspect ratio (etch depth to width) of up
19 to 30:1. Although not shown, any other reservoirs and/or channels, populated or
20 unpopulated, may also be formed by this etch sequence.

21 A film of positive-working photoresist is then deposited over the silicon dioxide
22 layer **502** and the exposed separation substrate **500** on the reservoir side **503** of the separation
23 substrate **500**. An area of the photoresist corresponding to the introduction channel which
24 will be subsequently etched is selectively exposed through a mask by an optical lithographic
25 exposure tool passing short-wavelength light, such as blue or near-ultraviolet at wavelengths
26 of 365, 405, or 436 nanometers. After development of the photoresist, the exposed area of
the photoresist corresponding to the introduction channel is removed and open to the
underlying separation substrate **500** while the unexposed areas remain protected by the
photoresist.

As shown in the plan and cross-sectional views of FIGS. 39A and 39B, respectively,
the exposed area of the separation substrate **500** is then vertically etched by a fluorine-based
plasma with a high degree of anisotropy and selectivity to the protective photoresist until the
silicon dioxide layer **504** on back side **505** is reached. Thus, a portion of the introduction
channel **404** is formed through the separation substrate **500**. The remaining photoresist is

1 removed in an oxygen plasma or in an actively oxidizing chemical bath like sulfuric acid
2 (H_2SO_4) activated with hydrogen peroxide (H_2O_2). The silicon dioxide layer **504** on the back
3 side **505** may then be removed by, for example, an unpatterned etch in a fluorine-based
4 plasma.

5 Alternatively, as shown in FIGS. 40A and 40B, the introduction channel **404** may
6 be formed by etching from both the reservoir side **503** and the back side **505** of the substrate
7 **500**. After performing a vertical etch through a portion of the substrate **500** to form a portion
8 of the introduction channel **404** in a manner similar to that described above, a film of
9 positive-working photoresist **512** is deposited on the silicon dioxide layer **504** on the back
10 side **505** of the separation substrate **500**. Patterns on the back side **505** may be aligned to
11 those previously formed on the reservoir side **503** of the separation substrate **500**. Because
12 silicon and its oxide are inherently relatively transparent to light in the infrared wavelength
13 range of the spectrum, i.e. approximately 700-1000 nanometers, the extant pattern on the
14 reservoir side **503** can be distinguished with sufficient clarity by illuminating the separation
15 substrate **500** from the patterned reservoir side **503** with infrared light. Thus, the mask for
16 the back side **505** can be aligned within required tolerances. Upon alignment, an area of the
17 photoresist **512** corresponding to the entrance orifice and the introduction channel which will
18 be subsequently etched is selectively exposed through a mask by an optical lithographic
19 exposure tool passing short-wavelength light, such as blue or near-ultraviolet at wavelengths
20 of 365, 405, or 436 nanometers.

21 After development of the photoresist **512**, the exposed area **514** of the photoresist
22 corresponding to the entrance orifice is removed to expose the underlying silicon dioxide
23 layer **504** on the back side **505** of the separation substrate **500** while the unexposed areas
24 remain protected by the photoresist **512**. The exposed area **514** of the silicon dioxide layer
25 **504** is then etched by a fluorine-based plasma with a high degree of anisotropy and
26 selectivity to the protective photoresist **512** until the substrate **500** is reached. The remaining
photoresist provides additional masking during a subsequent fluorine-based silicon etch to
vertically etch the backside portion of the introduction channel. Thus, a through-substrate
introduction channel **404** is complete. The remaining photoresist is removed in an oxygen
plasma or in an actively oxidizing chemical bath like sulfuric acid (H_2SO_4) activated with
hydrogen peroxide (H_2O_2).

Preferably, the introduction channel **404** has the same diameter as the entrance
orifice. A practical limit on etch aspect ratio of 30:1 constrains the diameter of the entrance
orifice being etched to be approximately 10 μm or greater for substrates of approximately

1 300 μm thickness. Preferably, the entrance orifice **406** and the introduction channel **404**
2 are approximately 100 μm in diameter due to practical considerations. For example, the
3 etch aspect ratio imposes a minimum diameter, and the diameter is preferably sufficiently
4 large to enable ease of filling the reservoir **410** yet sufficiently small to ensure a fluid surface
tension to prevent the fluid from leaking out of the reservoir **410**.

5 Alternatively, both the introduction channel and the entrance orifice may be formed
6 by etching from the back side **505** of the separation substrate **500**. This may be preferable
7 as it may be difficult to satisfactorily coat the separation posts **416** with photoresist. Further,
8 this may be desirable depending on the application of the device, e.g. the external sample
9 delivery system, the desired chip handling devices, the interfacing with other devices, chip-
10 based or non-chip based, and/or the packaging considerations of the chip. Referring to the
11 cross-sectional view of FIG. 41, after the reservoir, separation channel and the separation
12 posts are etched in the separation substrate **500** (shown in FIG. 38), a film of positive-
13 working photoresist **516** is deposited on the silicon dioxide layer **504** on the back side **505**
14 of the separation substrate **500**. Patterns on the back side **505** may be aligned to those
15 previously formed on the reservoir side **503** of the separation substrate **500** by illuminating
16 the separation substrate **500** from the patterned reservoir side **503** with infrared light, as
described above. Upon alignment, an area of the photoresist **516** corresponding to the
entrance orifice which will be subsequently etched is selectively exposed through a mask by
an optical lithographic exposure tool passing short-wavelength light, such as blue or near-
ultraviolet at wavelengths of 365, 405, or 436 nanometers.

17 After development of the photoresist **516**, the exposed area **518** of the photoresist
18 **516** corresponding to the entrance orifice is removed to expose the underlying silicon dioxide
19 layer **504** on the back side **505** of the separation substrate **500**. The exposed area **518** of the
20 silicon dioxide layer **504** is then etched by a fluorine-based plasma with a high degree of
21 anisotropy and selectivity to the protective photoresist **512** until the silicon separation
22 substrate **500** is reached. The remaining photoresist is left in place to provide additional
masking during the subsequent etch through the silicon separation substrate **500**.

23 Referring now to the cross-sectional view of FIG. 42, the introduction channel **404**
24 is vertically formed through the silicon separation substrate **500** by another fluorine-based
25 etch. The introduction channel **404** is completed by etching through the separation substrate
26 **500** until the reservoir **410** is reached. Thus, the introduction channel **404** extends through
the separation substrate **500** between the entrance orifice **406** on the back side **505** of the
separation substrate **500** and the reservoir **410**. The remaining photoresist is removed in an

1 oxygen plasma or in an actively oxidizing chemical bath like sulfuric acid (H_2SO_4) activated
2 with hydrogen peroxide (H_2O_2).

3 **Oxidation for surface passivation and fluid isolation**

4 As shown in the cross-sectional view of FIG. 43, a layer of silicon dioxide **522** is
5 grown on all silicon surfaces of the substrate **500** by subjecting the silicon substrate **500** to
6 elevated temperature in an oxidizing ambient. For example, the oxidizing ambient may be
7 an ultra-pure steam produced by oxidation of hydrogen for a silicon dioxide thickness greater
8 than approximately several hundred nanometers or pure oxygen for a silicon dioxide
9 thickness of approximately several hundred nanometers or less. The layer of silicon dioxide
10 **522** over all silicon surfaces of the separation substrate **500** electrically isolates a fluid in the
11 channel from the silicon substrate **500** and permits the application and sustenance of an
12 electric potential difference between the reservoir and the exit of the separation channel,
13 between the reservoir and an unpopulated portion of the separation channel near the reservoir
14 to facilitate in filling the reservoir and/or between other points along the fluid flow path.
15 Thus, the application and sustenance of a significant voltage across the fluid sample may be
16 achieved. Further, oxidation renders a surface inactive relative to a bare silicon surface,
17 resulting in surface passivation.

18 All silicon surfaces are oxidized to form silicon dioxide with a thickness that is
19 controllable through choice of temperature and time of oxidation. The final thickness of the
20 silicon dioxide can be selected to provide the desired degree of electrical isolation in the
21 device, where a thicker layer of silicon dioxide provides a greater resistance to electrical
22 breakdown.

23 Photolithography and reactive-ion etching limit the layout design of separation post
24 diameters and inter-post spacing to greater than approximately $1\text{ }\mu\text{m}$. However, because the
25 thermal oxidation process consumes approximately $0.44\text{ }\mu\text{m}$ of silicon to form each
26 micrometer of silicon dioxide, the thermal oxidation process results in a volumetric
expansion. This volumetric expansion may be utilized to reduce the spacing between the
separation posts **416** to sub-micrometer dimensions. For example, with a layout inter-post
spacing of approximately $1.5\text{ }\mu\text{m}$, oxidation producing a $1\text{ }\mu\text{m}$ silicon dioxide film or layer
would result in a nearest-neighbor spacing of approximately $0.5\text{ }\mu\text{m}$. Further, because the
oxidation process is well-controlled, separation post dimensions, including the inter-post
spacing, in the sub-micrometer regime can be formed reproducibly and in a high yielding
manner.

FIGS. 44A, 44B and 44C show scanning electron microscope photographs and design layout of portions of fabricated liquid chromatography devices. FIG. 44A shows a design layout of a portion of a reservoir and separation posts in a portion of a separation channel where the separation posts have rectangular cross-sectional shape. FIG. 44B shows separation posts in a portion of a separation channel, the separation posts having a circular cross-sectional shape and a diameter and inter-post spacing of approximately 1 μm . FIG. 44C shows separation posts in a portion of a separation channel, the separation posts having a rectangular or square cross-sectional shape with a dimension of 2 μm and inter-post spacing of approximately 1 μm .

In a variation, the entrance orifice and the introduction channel for filling the fluid reservoir may be formed in the cover substrate 524 after a layer of silicon dioxide 525 is grown on all surfaces of the cover substrate 524, rather than in the substrate 500. As shown in FIG. 45, the cover substrate 524 may be bonded to the reservoir side 503 of the separation substrate 500. The entrance orifice 406' and the introduction channel 404' may be formed in the cover substrate 524 after alignment with respect to the reservoir 410. The entrance orifice 406' and the introduction channel 404' may be formed in the same or similar manner as described above by utilizing lithography to define the entrance orifice pattern and reactive-ion etching to create the entrance orifice and the through-cover introduction channel. The cover substrate 524 is again subjected to elevated temperature in an oxidizing ambient to grow a layer of oxide on the surface of the introduction channel 404'. Further, the introduction channel 404' may be formed from one or two sides of the cover substrate 524. If channel 404' is formed from two sides of the cover substrate, the cover substrate 524 may be bonded to substrate 500 after forming the channel 404' and after oxidation of the channel surface. One advantage of defining the entrance orifice on the same side of the completed liquid chromatography device as the reservoir and separation channel is that the back side of the substrate 500 is then free from any features and may then be bonded to a protective package without special provision for filling the reservoir through an entrance orifice defined on the back-side of the substrate.

Metallization for fluid flow control

FIGS. 46A and 46B illustrate the formation of a reservoir, a filling, and an exit electrode as well as conductive lines or wires connecting the electrodes to bond pads in the cover substrate 526, preferably comprising glass and/or silicon. The cover substrate 526 shown in FIGS. 46A and 46B does not provide an entrance orifice or an introduction channel

1 although the metallization process described herein may be easily adapted for a cover
2 substrate providing an entrance orifice and an introduction channel.

3 As shown in the plan and cross-sectional view of FIGS. 46A and 46B, respectively,
4 prior to the depositing of conductive material on the cover substrate **526**, all surfaces of the
5 cover substrate **526** are subjected to thermal oxidization in a manner that is the same as or
6 similar to the process described above to create a film or layer of silicon dioxide **528**. Such
7 oxidization is not performed where the cover substrate **526** comprises glass.

8 The silicon dioxide layer **528** provides a surface on which conductive electrodes may
9 be formed. The thickness of the silicon dioxide layer **528** is controllable through the
10 oxidation temperature and time and the final thickness can be selected to provide the desired
11 degree of electrical isolation, where a thicker layer of silicon dioxide provides a greater
12 resistance to electrical breakdown. The silicon dioxide layer **528** electrically isolates all
13 electrodes from the cover substrate **526** and isolates the fluid in the reservoir and the channel
14 of the liquid chromatography device from the cover substrate **526**. The ability to isolate the
15 fluid from the cover substrate **526** complements the electrical isolation provided in the
16 separation substrate through oxidation and ensures the complete electrical isolation of the
17 fluid from both the separation substrate and the cover substrate **526**. The complete electrical
18 isolation of the sample fluid from both substrates allows for the application of electric
19 potential differences between spatially separated locations in the fluidic flow path resulting
20 in control of the fluid flow through the path.

21 The cover substrate **528** may be cleaned after oxidation utilizing an oxidizing
22 solution such as an actively oxidizing chemical bath, for example, sulfuric acid (H_2SO_4)
23 activated with hydrogen peroxide (H_2O_2). The cover substrate **528** is then thoroughly rinsed
24 to eliminate organic contaminants and particulates. A layer of conductive material **530** such
25 as aluminum is then deposited by any suitable method such as by DC magnetron sputtering
26 in an argon ambient. The thickness of the aluminum is preferably approximately 3000 Å,
although shown having a larger thickness for clarity. Although aluminum is utilized in the
fabrication sequence described herein, any type of highly conductive material such as other
metals, metallic multi-layers, silicides, conductive polymers, and conductive ceramics like
indium tin oxide (ITO) may be utilized for the electrodes. The surface preparation for
satisfactory adhesion may vary depending on the specific electrode material used. For
example, the silicon dioxide layer **528** provides a surface to which aluminum electrodes may
adhere as aluminum does not generally adhere well to native silicon.

1 A film of positive-working photoresist **532** is then deposited over the surface of the
2 conductive material **530**. Areas of the photoresist layer **532** corresponding to areas
3 surrounding the electrodes (shown) and conductive lines or wires and bond pads which will
4 be subsequently etched are selectively exposed through a mask by an optical lithographic
5 exposure tool passing short-wavelength light, such as blue or near-ultraviolet at wavelengths
of 365, 405, or 436 nanometers.

6 After development of the photoresist **532**, the exposed areas of the photoresist are
7 removed, leaving opening to the underlying aluminum conductive layer **530** while the
8 unexposed areas **534**, **536**, **538** corresponding to the reservoir, filling and exit electrodes,
9 respectively, as well as conductive lines or wires and bond pads remain protected by the
10 photoresist. The conductive electrodes and the lines/bond pads may be etched, such as by
11 a wet chemical etch or a reactive-ion etch, as appropriate for the particular conductive
12 material. The etch is selective to the underlying silicon dioxide layer **528** or is terminated
13 upon reaching the silicon dioxide layer **528** as determined by the etch time and rate. The
14 remaining photoresist is removed in an oxygen plasma or in a solvent bath such as acetone.
15 The fabrication sequence thus results in physically and electrically separate islands of
16 conductive electrodes, lines and bond pads according to the pattern designed in the mask.

17 The cover substrate may be larger than the separation substrate to allow access to
18 the bond pads and/or directly to the electrodes for the application of potential voltage(s) to
19 the electrode(s). As shown in FIG. 46C, the cover substrate **526'** is larger than the separation
20 substrate such that the separation substrate only extends to dashed line **540** relative to the
21 cover substrate **526'**. Conductive lead-throughs such as connecting metal lines **542**, **544** and
22 **546** extend from the reservoir, filling and exit electrodes, **534**, **536**, **538**, respectively, and
23 enable the application of potential voltage(s) to the electrode(s).

24 Alternatively, a metal lead may be formed from each electrode to an otherwise
25 unpatterned area of the separation substrate such that a through-substrate access channel
26 formed in the cover substrate and filled with a conductive material by chemical vapor
deposition (CVD) allows access to the electrode(s). As an alternative to chemical vapor
deposition, the sidewalls of the through-substrate access channel may be sloped, for example
by KOH etch, to facilitate continuous deposition of a conductive material thereon, thereby
providing an electrically continuous path from the separation substrate to the top of the cover
substrate where potential voltages can be applied. In these variations, the separation and the
cover substrates may be of the same size.

1 Although the electrodes are preferably provided on a surface of the cover substrate,
2 the electrodes may be alternatively and/or additionally provided on the separation substrate
3 by appropriate modifications to the above-described fabrication process. For example, in
4 such a variation, the side walls of the reservoir are preferably not at a 90° angle relative to
5 the bottom wall and can be formed at least in part by, for example, a wet chemical potassium
6 hydroxide (KOH) etch. The sloped reservoir side walls allow for the deposition of a
7 conductive material thereon. In another variation, the electrodes may also be formed by a
8 damascene process, known in the art of semiconductor fabrication. The damascene process
9 provides the advantage of a planar surface without the step up and step down surface
10 topography presented by a bond line or pad and thus facilitates the bonding of the separation
11 and cover substrate, as described below.

12 The above described fabrication sequence for the liquid chromatography device may
13 be easily adapted to and is applicable for the simultaneous fabrication of a monolithic system
14 comprising multiple liquid chromatography devices including multiple reservoirs and/or
15 multiple separation channels as described above embodied in a single monolithic substrate.

16 Further, although the fabrication sequence is described in terms of fabricating a
17 single liquid chromatography device, the fabrication sequence facilitates and allows for
18 massively parallel processing of similar devices. The multiple liquid chromatography
19 devices or systems fabricated by massively parallel processing on a single wafer may then
20 be cut or otherwise separated into multiple devices or systems.

21 Although control of the liquid chromatography device has been described above as
22 comprising reservoir, filling and exit electrodes, any suitable combination of such and/or
23 other electrodes in electrical contact with the fluid in the fluid path may be provided and
24 easily fabricated by modifying the layout design. Further, any or all of the electrodes may
25 be additionally or alternatively provided in the separation substrate. Electrodes may be
26 formed in the separation substrate by modifying the fabrication sequence to include
additional steps similar to or the same as the steps as described above with respect to the
formation of the electrodes in the cover substrate.

Bonding cover substrate to separation substrate

As described above, the cover substrate is preferably hermetically bonded by any
suitable method to the separation substrate for containment and isolation of the fluid in the
liquid chromatography device. Examples of bonding silicon to silicon or glass to silicon
include anodic bonding, sodium silicate bonding, eutectic bonding, and fusion bonding.

1 For example, to bond the separation substrate to a glass cover substrate by anodic
2 bonding, the separation substrate and cover substrate are heated to approximately 400°C and
3 a voltage of 400-1200 Volts is applied, with the separation substrate chosen as the anode (the
4 higher potential). Further, as the required bonding voltage depends on the surface oxide
5 thickness, it may be desirable to remove the oxide film or layer from the back side 505 of the
6 separation substrate prior to the bonding process in order to reduce the required bonding
7 voltage. The oxide film or layer may be removed by, for example, an unpatterned etch in a
8 fluorine-based plasma. The etch is continued until the entire oxide layer has been removed,
9 and the degree of over-etch is unimportant. Thus, the etch is easily controlled and high-
10 yielding.

11 Critical considerations in any of the bonding methods include the alignment of
12 features in the separation and the cover substrates to ensure proper functioning of the liquid
13 chromatography device after bonding and the provision in layout design for conductive lead-
14 throughs such as the bond pads and/or metal lines so that the electrodes (if any) are
15 accessible from outside the liquid chromatography device. Another critical consideration is
16 the topography created through the fabrication sequence which may compromise the ability
17 of the bonding method to hermetically seal the separation and cover substrates. For example,
18 the step up and step down in the surface topography presented by a metal line or pad may be
19 particularly difficult to form a seal therearound as the silicon or glass does not readily deform
20 to conform to the shape of the metal line or pad, leaving a void near the interface between
21 the metal and the oxide.

22 **INTEGRATION OF LIQUID CHROMATOGRAPHY AND ELECTROSPRAY** 23 **DEVICES ON A CHIP**

24 The cross-sectional schematic view of FIG. 47 shows a liquid chromatography-
25 electrospray system 600 comprising a liquid chromatography device 602 of the present
26 invention integrated with an electrospray device 620 of the present invention such that a
homogeneous interface is formed between the exit orifice 614 of the liquid chromatography
device 602 and the entrance orifice 622 of the electrospray device 620. The single integrated
system 600 allows for the fluid exiting the exit orifice 614 of the liquid chromatography
device 602 to be delivered on-chip to the entrance orifice 622 of the electrospray device 620
in order to generate an electrospray.

As shown in FIG. 47, the entrance orifice 606 and the introduction channel 604

1 of the liquid chromatography device 602 are formed in the cover substrate 608 along with
2 the electrospray device 620. Alternatively, the liquid chromatography entrance orifice and
the introduction channel may be formed in the separation substrate.

3 Fluid at the electrospray nozzle entrance 622 is at the exit voltage applied to the exit
4 electrode 610 in the separation channel 612 near the liquid chromatography exit orifice 614.
5 Thus, an electrospray entrance electrode is not necessary.

6 The single integrated system 600 provides the advantage of minimizing or
eliminating extra fluid volume to reduce the risk of undesired fluid changes, such as by
7 reactions and/or mixing. The single integrated system 600 also provides the advantage of
8 eliminating the need for unreliable handling and attachment of components at the
microscopic level and of minimizing or eliminating fluid leakage by containing the fluid
9 within one integrated system.

10 The integrated liquid chromatography-electrospray system 600 may be utilized to
11 deliver liquid samples to the sampling orifice of a mass spectrometer. The sampling orifice
12 of the mass spectrometer may serve as an extraction electrode in the electrospray process
when held at an appropriate voltage relative to the voltage of the electrospray nozzle 624.
13 The liquid chromatography-electrospray system 600 may be positioned within 10 mm of the
14 sampling orifice of the mass spectrometer for efficient extraction of the fluid from the
electrospray nozzle 624.

15 **Multiple liquid chromatography-electrospray systems on a single chip**

16 Multiples of the liquid chromatography-electrospray system 600 may be formed on
17 a single chip to deliver a multiplicity of samples to a common point for subsequent
sequential analysis. For example, FIG. 48 shows a plan view of multiple liquid
18 chromatography-electrospray systems 600 on a single chip 650 and FIG. 49 shows a detailed
19 view of area A of systems 600 with the separation channels shown in phantom and without
the recessed portions for purposes of clarity. As shown, the multiple nozzles 624 of the
20 electrospray devices 620 may be radially positioned about a circle having a relatively small
21 diameter near the center of the single chip 650. The dimensions of the electrospray nozzles
22 and the liquid chromatography channels limit the radius at which multiple nozzles are
positioned on the multi-system chip 650. For example, the multi-system chip may provide
23 96 nozzles with widths of up to 50 μm positioned around a circle 2 mm in diameter such that
24 the spacing between each pair of nozzles is approximately 65 μm .

25 Alternatively, an array of multiple electrospray devices without liquid
26 chromatography devices may be formed on a single chip to deliver a multiplicity of

1 samples to a common point for subsequent sequential analysis. The nozzles may be similarly
2 radially positioned about a circle having a relatively small diameter near the center of the
3 chip. The array of electrospray devices on a single microchip may be integrated upstream
4 with multiple fluid delivery devices such as separation devices fabricated on a single
5 microchip. For example, an array of radially distributed exit orifices of a radially distributed
6 array of micro liquid chromatography columns may be integrated with radially distributed
7 entrance orifices of electrospray devices such that the nozzles are arranged at a small radius
8 near the orifice of a mass spectrometer. Thus, the electrospray devices may be utilized for
9 rapid sequential analysis of multiple sample fluids. However, depending upon the specific
10 application and/or the capabilities of the downstream mass spectrometer (or other
11 downstream device), the multiples of the electrospray devices may be utilized one at a time
or simultaneously, either all or a portion of the electrospray devices, to generate one or more
electrosprays. In other words, the multiples of the electrospray devices may be operated in
parallel, staggered or individually.

12 The single multi-system chip 650 may be fabricated entirely in silicon substrates,
13 thereby taking advantage of well-developed silicon processing techniques described above.
14 Such processing techniques allow the single multi-system chip 650 to be fabricated in a cost-
15 effective manner, resulting in a cost performance that is consistent with use as a disposable
16 device to eliminate cross-sample contamination. Furthermore, because the dimensions and
17 positions of the liquid chromatography-electrospray systems are determined through layout
design rather than through processing, the layout design may be easily adapted to fabricate
multiple liquid chromatography-electrospray systems on a single chip.

18 **Interface of a multi-system chip to mass spectrometer**

19 The radially distributed array of electrospray nozzles 624 on a multi-system chip
20 may be interfaced with a sampling orifice of a mass spectrometer by positioning the nozzles
21 near the sampling orifice. The tight radial configuration of the electrospray nozzles 624
allows the positioning thereof in close proximity to the sampling orifice of a mass
spectrometer.

22 The multi-system chip 650 may be rotated relative to the sampling orifice to position
23 one or more of the nozzles for electrospray near the sampling orifice. Appropriate voltage(s)
24 may then be applied to the one or more of the nozzles for electrospray. Alternatively, the
25 multi-system chip 650 may be fixed relative to the sampling orifice of a mass spectrometer
26 such that all nozzles, which converge in a relatively tight radius, are appropriately
positioned for the electrospray process. As is evident, eliminating the need for nozzle

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

repositioning allows for highly reproducible and quick alignment of the single multi-system chip and increases the speed of the analyses.

One, some or all of the radially distributed nozzles **624** of the electropray devices **620** may generate electrosprays simultaneously, sequentially or randomly as controlled by the voltages applied to the appropriate electrodes of the electropray device **620**.

While specific and preferred embodiments of the invention have been described and illustrated herein, it will be appreciated that modifications can be made without departing from the spirit of the invention as found in the appended claims.

What is claimed and desired to be secured by United States Letters Patent is:

- 1 1. An integrated miniaturized system for chemical analysis of fluids, comprising:
2 an electrospray substrate having an injection side and an ejection surface, the
3 substrate defining an entrance orifice on the injection side, a nozzle on the ejection
4 surface, a channel extending between the entrance orifice and the nozzle, and a
5 region surrounding the nozzle recessed from the ejection surface; and
6 electrode means for providing electrical contact to the fluids.
- 7 2. The system of claim 1, wherein said electrode means comprises an external
8 conductor in contact with the fluid prior to said injection side.
- 9 3. The system of claim 1, wherein the channel has a cross-sectional area less than
10 approximately 50,000 μm^2 .
- 11 4. The system of claim 1, wherein the substrate defines a plurality of entrance
12 orifices on the injection side, a plurality of nozzles on the ejection surface each
13 corresponding to one of the plurality of entrance orifices, a plurality of channels each
14 extending between one of the plurality of nozzles and the corresponding one of the plurality
15 of entrance orifices.
- 16 5. The system of claim 4, wherein an array of said plurality of nozzles are radially
17 positioned on the ejection surface of the electrospray substrate.
- 18 6. The system of claim 1, further comprising a device in fluid communication with
19 the entrance orifice.
- 20 7. The system of claim 1, wherein an array of nozzles are defined on the ejection
21 surface of the electrospray substrate, and further comprising a daughter plate defining a
22 plurality of receiving wells positioned to receive a fluid ejected through the nozzles of the
23 electrospray substrate.
- 24 8. The system of claim 1, further comprising a second substrate defining an
25 entrance opening on a first surface and an exit on a second surface, the second substrate
26 being bonded to the electrospray substrate such that the second substrate exit is in fluid
 communication with the electrospray substrate entrance orifice.
9. The system of claim 1, further comprising a second substrate defining an
 entrance opening on a first surface, an exit on a second surface, a fluid reservoir recessed
 from the second surface, a separation channel recessed from the second surface, the
 separation channel including the exit and extending between the reservoir and the exit, an
 introduction channel extending between the entrance opening and the reservoir, and a
 plurality of posts extending from the separation channel, wherein the second substrate is
 bonded to the electrospray substrate to enclose the reservoir and the separation channel

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

adjacent the electrospray substrate and such that the second substrate exit is in fluid communication with the electrospray substrate entrance orifice.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

10. An electrospray device comprising:
an array of nozzles integrated in a substrate for ejecting a plurality of analytes at a mass spectrometry device interface; and
a plurality of electrodes for the application of electric potentials for generating and controlling an electric field at each nozzle to direct the ejection of the analytes from the nozzles within an acceptance region of the mass spectrometry device.

11. A method for generating an electrospray of a fluid, comprising:
- providing a channel extending between an entrance orifice defined on an injection surface of a substrate and a nozzle defined on an ejection surface of the substrate;
 - introducing a fluid into the channel through the entrance orifice;
 - providing a first electrode in electrical contact with the fluid;
 - applying a first potential voltage to the fluid;
 - positioning the nozzle adjacent to an extracting electrode; and
 - ejecting the fluid from the channel through the nozzle by applying or holding the extracting electrode at a second potential voltage different from the first potential voltage.
12. The method of claim 11, further comprising:
- providing a second electrode in electrical contact with the substrate; and
 - applying a third potential voltage to said second electrode, different from said first potential voltage.

1 13. A liquid chromatography system, comprising:

2 a first substrate having a first surface and a second surface, the first substrate
3 defining an entrance opening on the first surface, a fluid reservoir recessed from the
4 second surface, a first channel extending between the entrance opening and the
5 reservoir, a second channel recessed from the second surface, and a plurality of
6 posts extending from the second channel; and

7 a cover substrate bonded to the first substrate to enclose the reservoir and the
8 second channel adjacent the cover substrate,

9 wherein the first and/or the cover substrate defines an exit and wherein the
10 second channel extends between the exit and the reservoir.

11 14. The liquid chromatography system of claim 13, further comprising an
12 insulating layer provided over the surfaces of the separation channel and the plurality of
13 posts.

14 15. The liquid chromatography system of claim 13, wherein the posts are spaced
15 apart from each other by no more than 5 μ m.

16 16. The liquid chromatography system of claim 13, wherein the first substrate
17 defines a plurality of entrance openings on the first surface, a plurality of reservoirs recessed
18 from the second surface each corresponding to one of the plurality of entrance openings, one
19 or more first channels each corresponding to and extending between one of the plurality of
20 entrance openings and the corresponding reservoir, and a plurality of second channels
21 recessed from the second surface, wherein the first and/or the cover substrate defines a
22 plurality of exits each corresponding to one of the plurality of reservoirs, and wherein each
23 second channel corresponds to and extends between one of the plurality of reservoirs and the
24 corresponding exit.

17. A chemical separation device comprising:
a substrate defining a channel,
a plurality of posts fabricated from said substrate and extending from said
channel, and
a stationary phase bound to the posts, said posts providing interaction with
an analyte introduced into said channel for producing separation.

1 18. An integrated chemical analysis system, comprising:

2 a first substrate having a major surface;

3 a second substrate bonded to or otherwise attached to said first substrate;

4 a liquid chromatography system integrated in said second substrate, and
configured to receive a fluid for analysis and to process and output the fluid; and

5 an electrospray device integrated on said first substrate, the electrospray
device having an injection surface configured to receive the processed fluid from the
6 liquid chromatography system, the major surface being configured to dispense the
7 fluid by electrospraying the fluid.

8 19. The system of claim 18, wherein the major surface of the electrospray device
is configured to dispense the processed fluid in a direction generally perpendicular to the
9 major surface.

10 20. The system of claim 18, wherein a plurality of liquid chromatography systems
are each integrated in said second substrate, and each configured to receive a
11 fluid for analysis and to process and output the fluid; and a plurality of electrospray devices,
each integrated on said first substrate, the electrospray devices each having an injection
12 surface configured to receive the processed fluid from the liquid chromatography system, and
each having an ejection surface configured to dispense the fluid by electrospraying the fluid.
13
14
15
16
17
18
19
20
21
22
23
24
25
26

21. A system comprising:

a microfabricated device defining a liquid chromatography device comprising an entrance for receiving an analyte, the device further defining an electrospray device including a nozzle, the electrospray device being configured to receive the analyte from the liquid chromatography device and to generate an electrospray; and

a mass spectrometer comprising a sampling orifice, said microfabricated device being positioned to eject the electrospray from the nozzle into the sampling orifice.

ABSTRACT

An electrospray device, a liquid chromatography device and an electrospray-liquid chromatography system are disclosed. The electrospray device comprises a substrate defining a channel between an entrance orifice on an injection surface and an exit orifice on an ejection surface, a nozzle defined by a portion recessed from the ejection surface surrounding the exit orifice, and an electrode for application of an electric potential to the substrate to optimize and generate an electrospray; and, optionally, additional electrode(s) to further modify the electrospray. The liquid chromatography device comprises a separation substrate defining an introduction channel between an entrance orifice and a reservoir and a separation channel between the reservoir and an exit orifice, the separation channel being populated with separation posts perpendicular to the fluid flow; a cover substrate bonded to the separation substrate to enclose the reservoir and the separation channel adjacent the cover substrate; and, optionally, electrode(s) for application of a electric potential to the fluid. The exit orifice of the liquid chromatography device may be homogeneously interfaced with the entrance orifice of the electrospray device to form an integrated single system. An array of multiple systems may be fabricated in a single monolithic chip for rapid sequential fluid processing and generation of electrospray for subsequent analysis, such as by positioning the exit orifices of the electrospray devices near the sampling orifice of a mass spectrometer.

G:\DATA\PAT\1491714.PAT

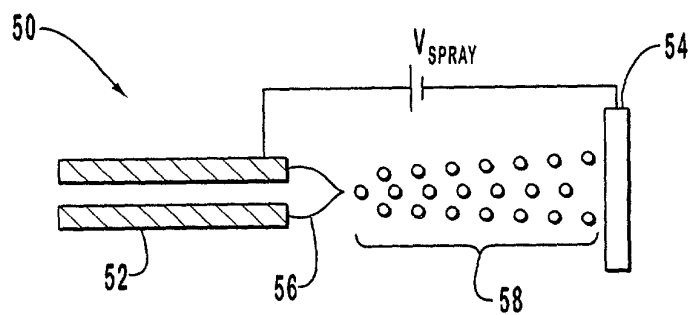


FIG. 1

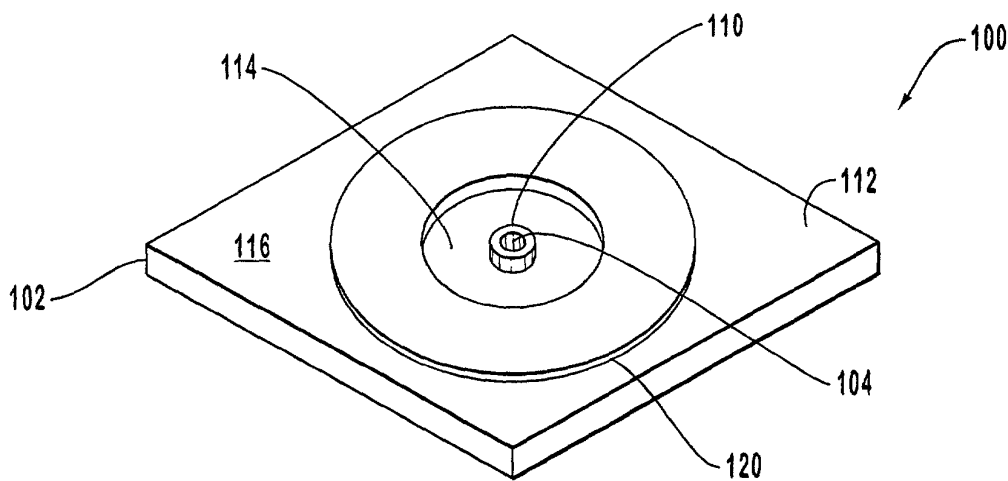


FIG. 2

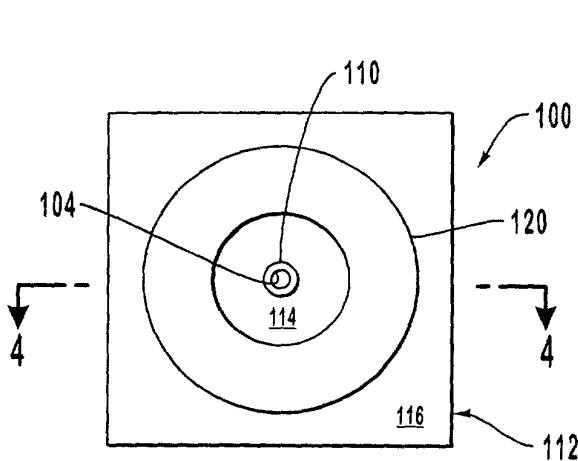


FIG. 3

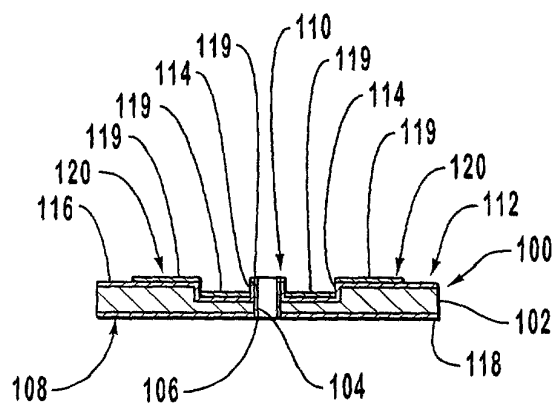


FIG. 4

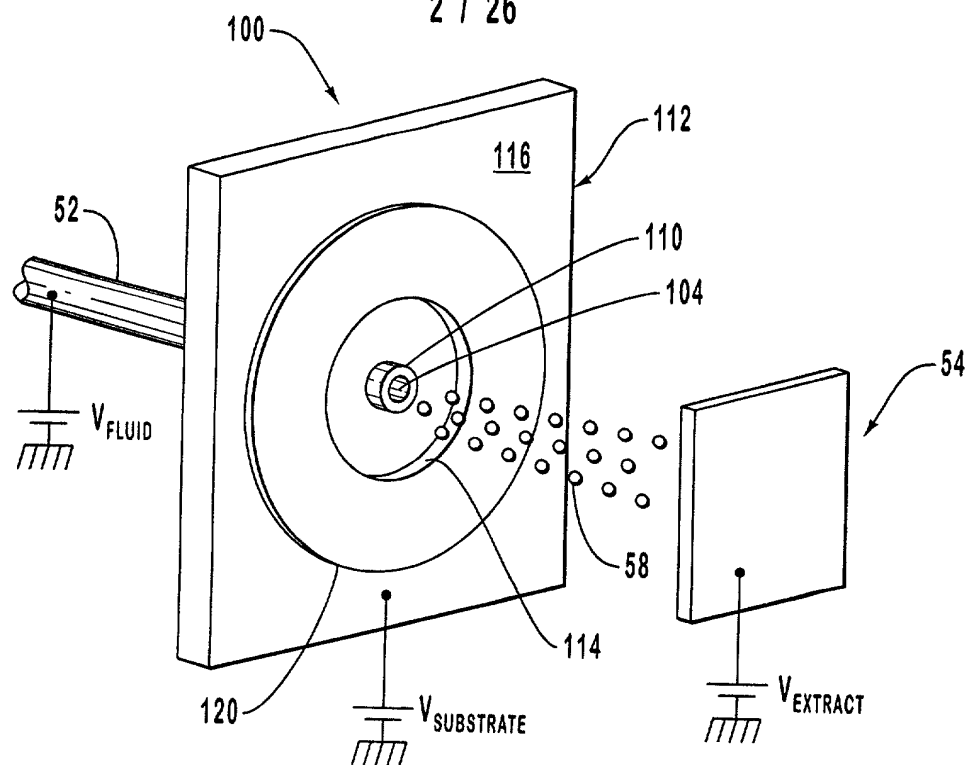


FIG. 5

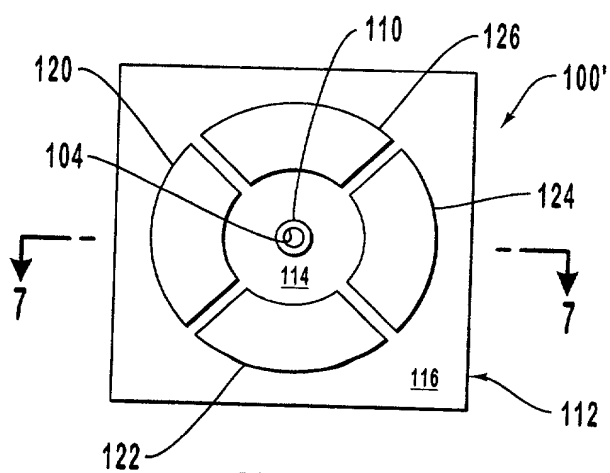
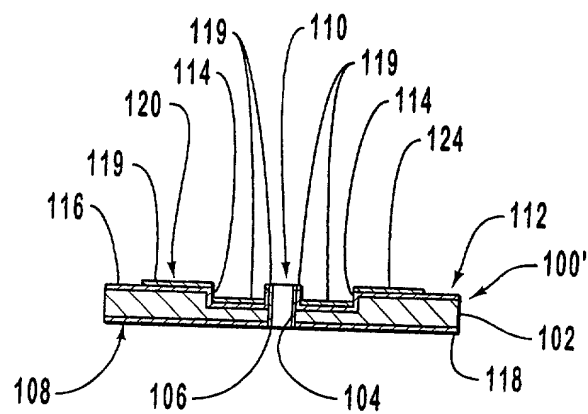


FIG. 6



710 7

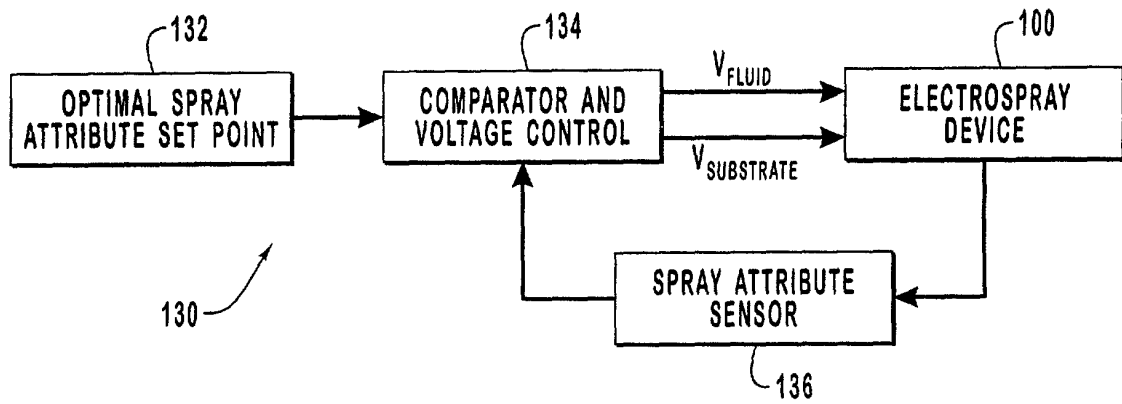


FIG. 8

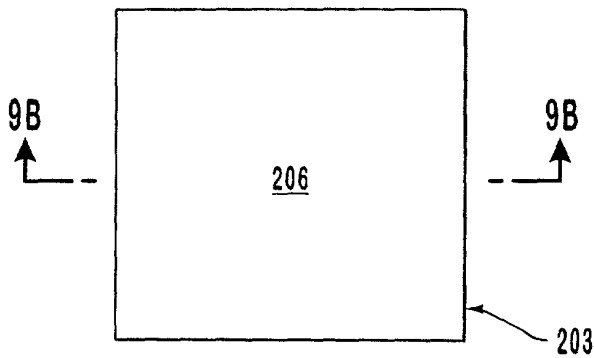


FIG. 9A

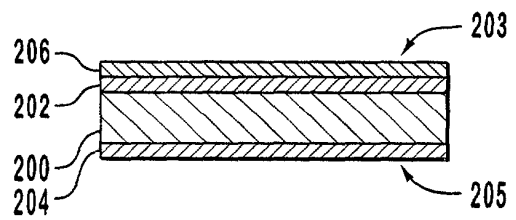
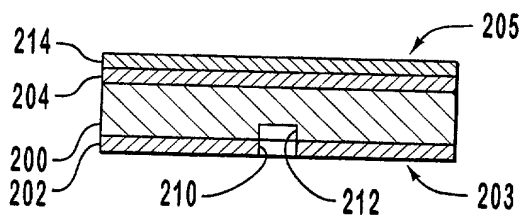
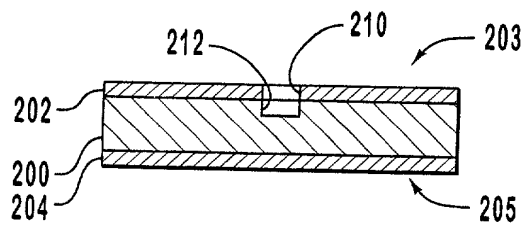
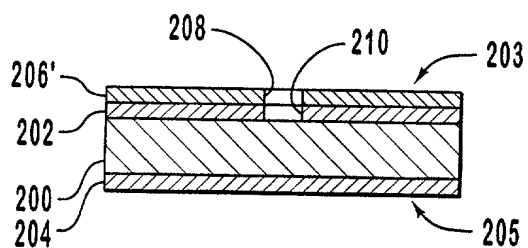
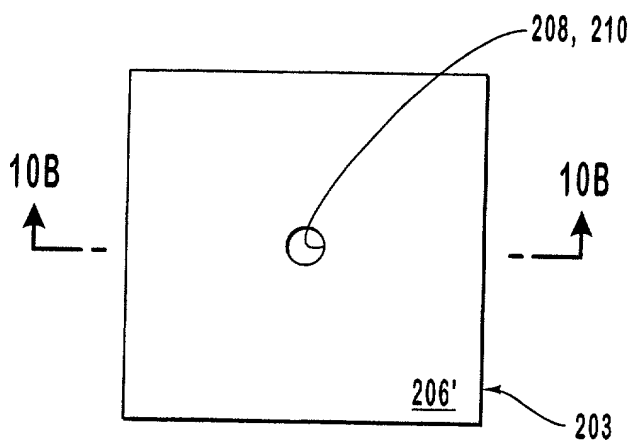


FIG. 9B



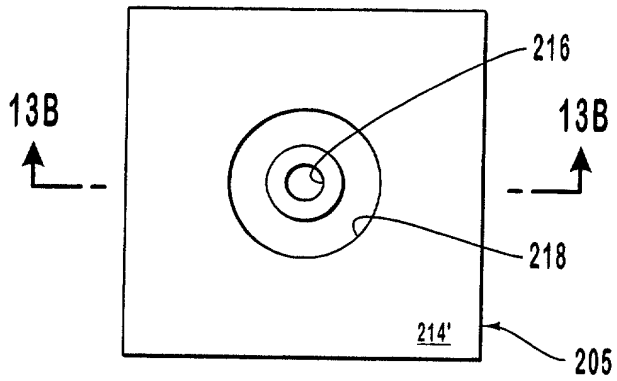


FIG. 13A

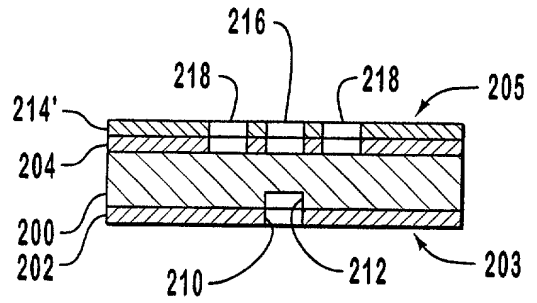


FIG. 13B

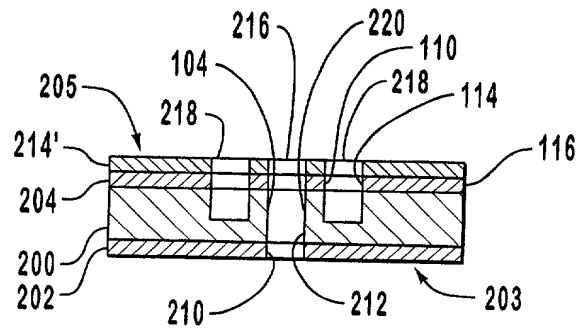


FIG. 14

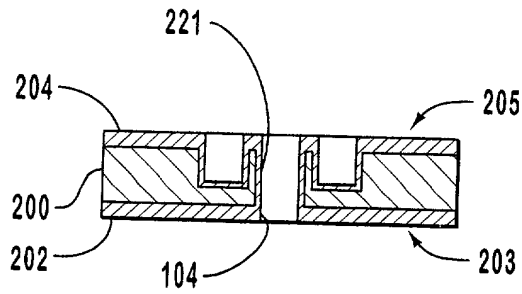


FIG. 15

FIG. 16

FIG. 17

FIG. 18

FIG. 19

FIG. 20A

FIG. 20B

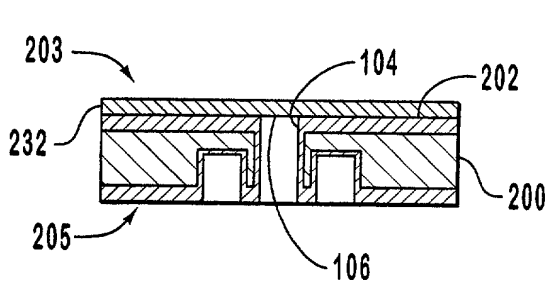


FIG. 20C

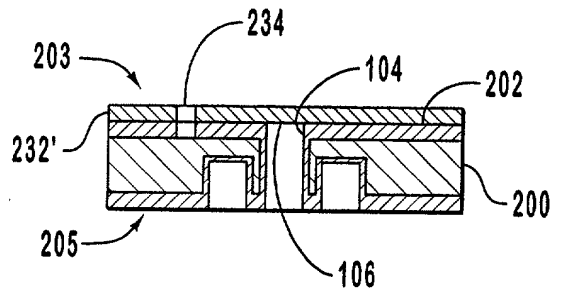


FIG. 20D

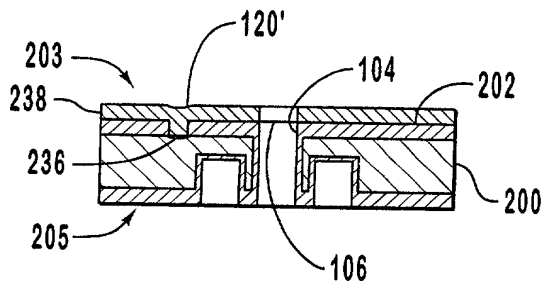


FIG. 20E

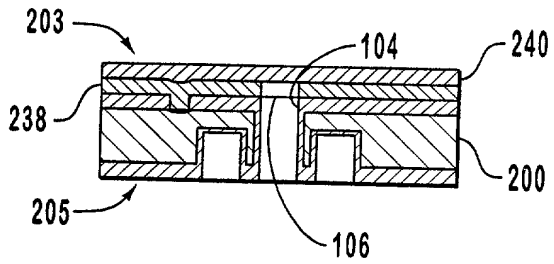


FIG. 20F

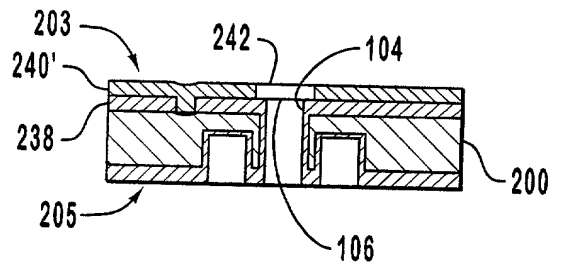


FIG. 20G

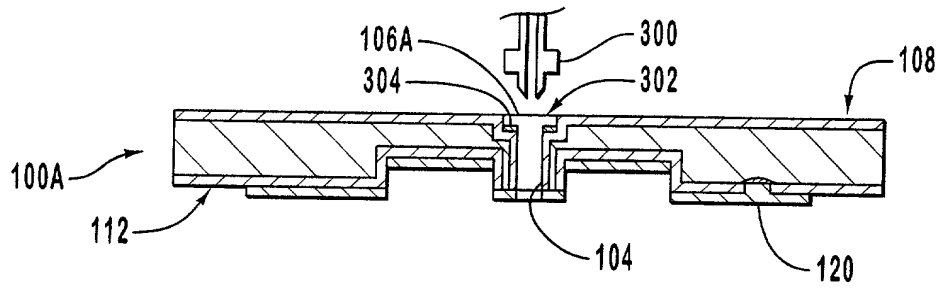


FIG. 21A

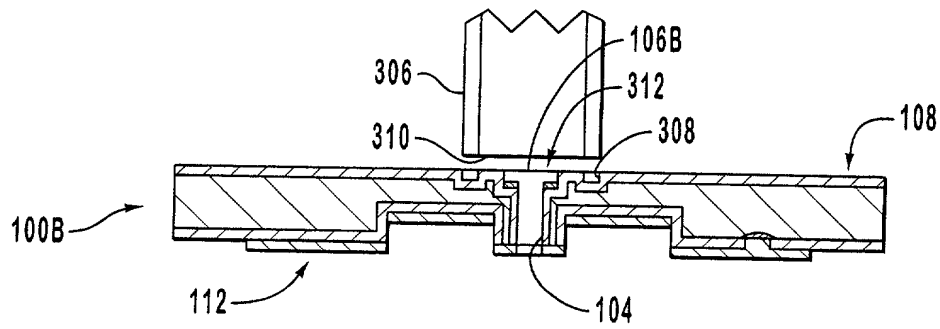


FIG. 21B

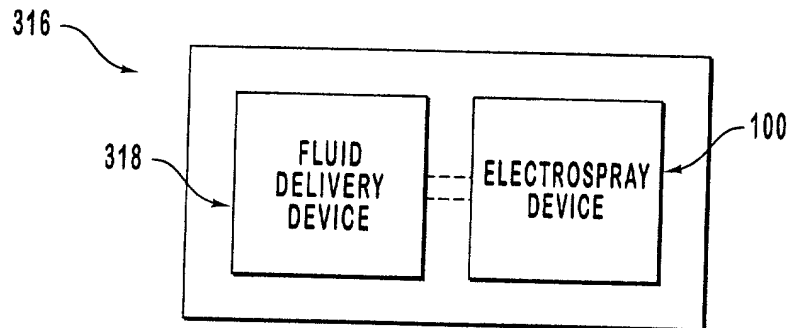


FIG. 22

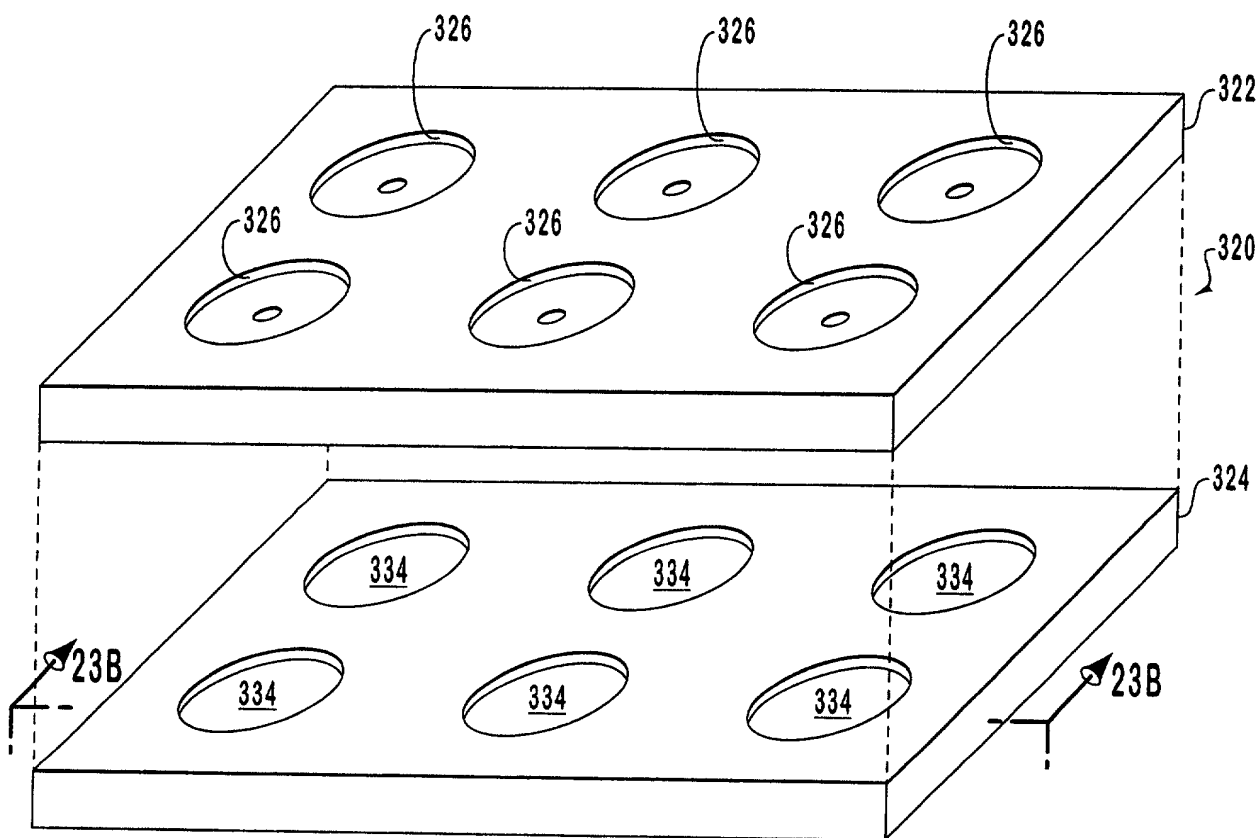


FIG. 23A

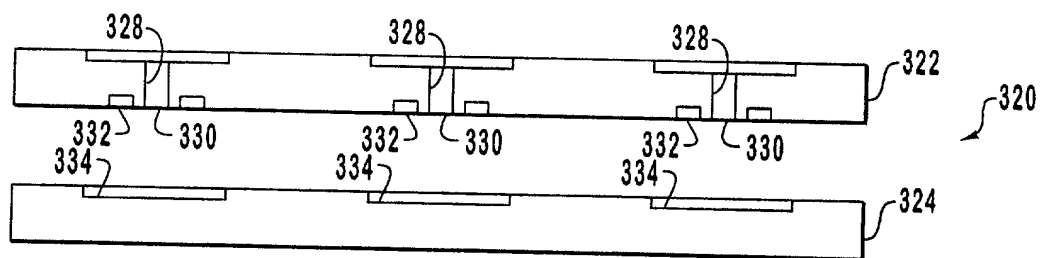


FIG. 23B

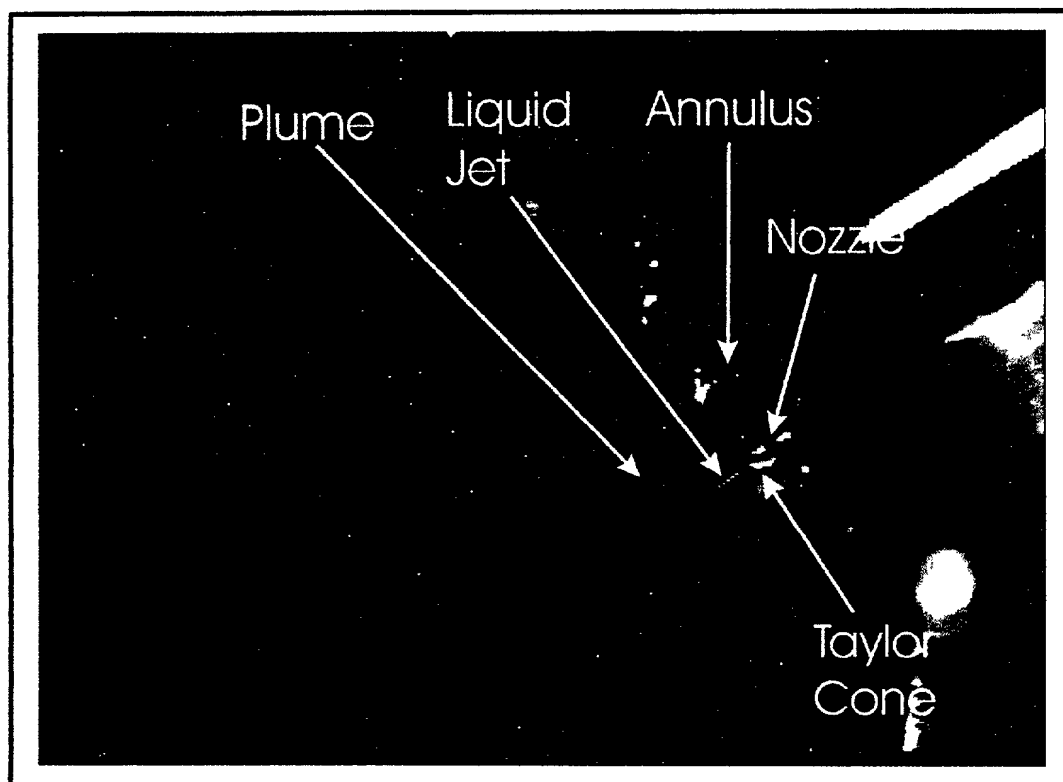
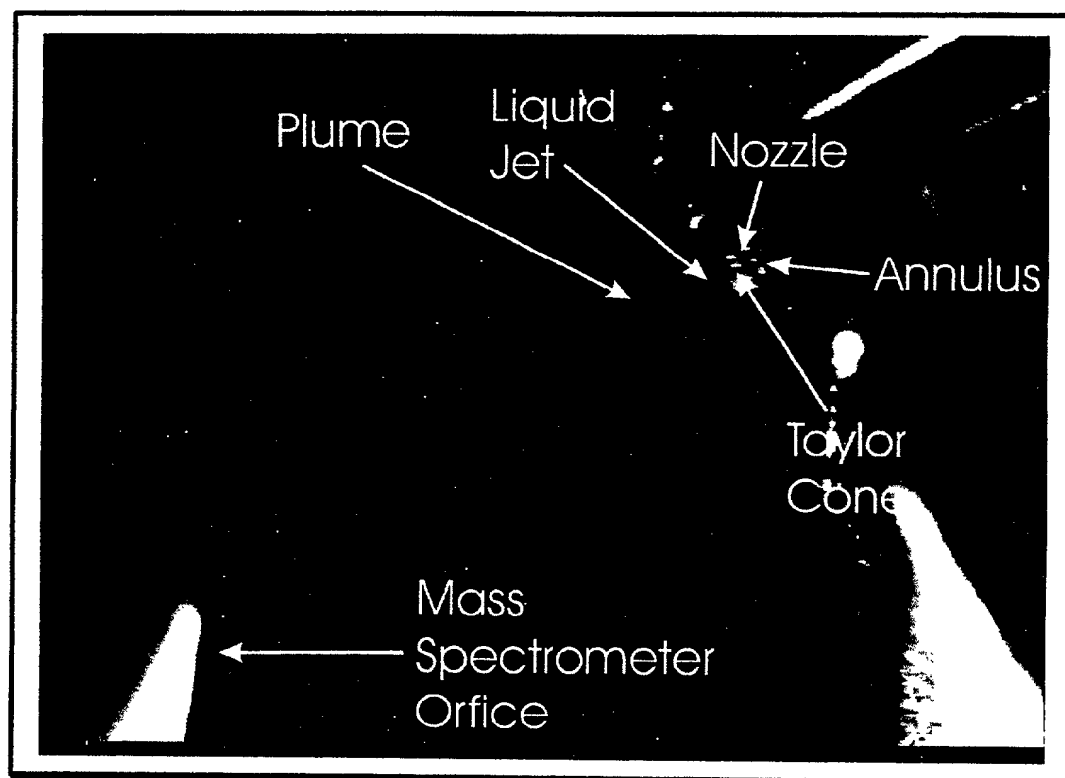
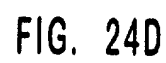
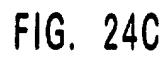


FIG. 24A



EIC 2AR

Parameter	Value	Unit
α	0.001	
β	0.001	
γ	0.001	
δ	0.001	
ϵ	0.001	
ζ	0.001	
η	0.001	
θ	0.001	
ι	0.001	
κ	0.001	
λ	0.001	
μ	0.001	
ν	0.001	
ξ	0.001	
\omicron	0.001	
π	0.001	
ρ	0.001	
σ	0.001	
τ	0.001	
υ	0.001	
ϕ	0.001	
χ	0.001	
ψ	0.001	
ω	0.001	
Ω	0.001	
Θ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	
Ψ	0.001	
Ξ	0.001	
\Omicron	0.001	
Π	0.001	
Σ	0.001	
Υ	0.001	
Φ	0.001	





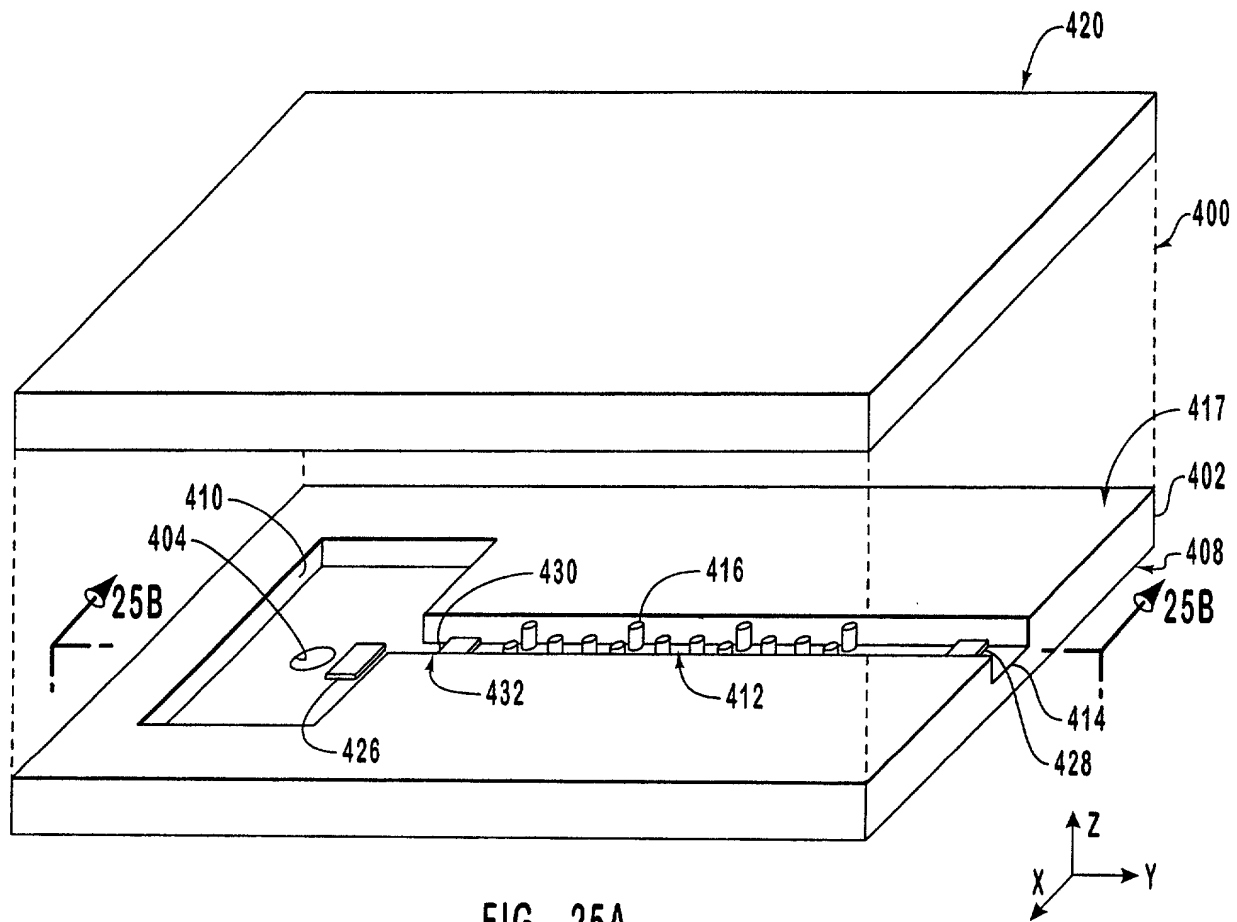


FIG. 25A

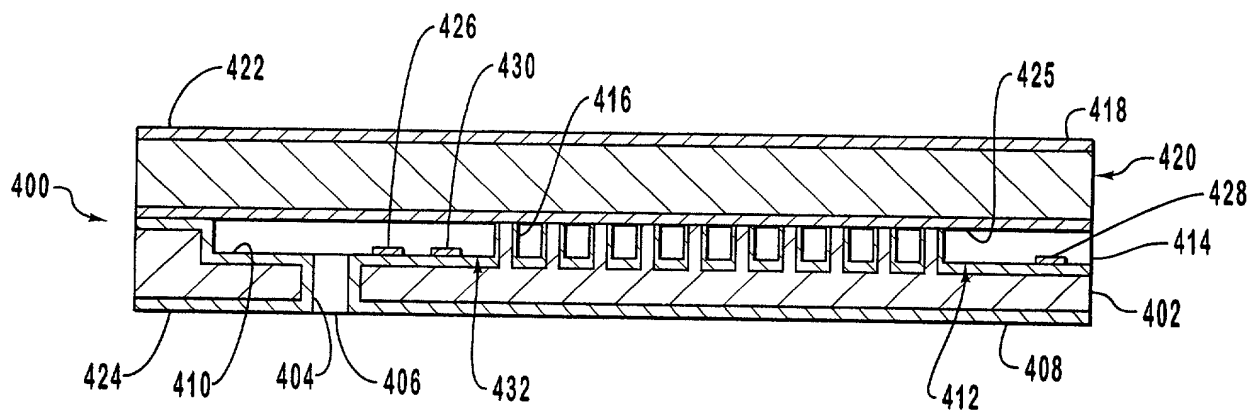


FIG. 25B

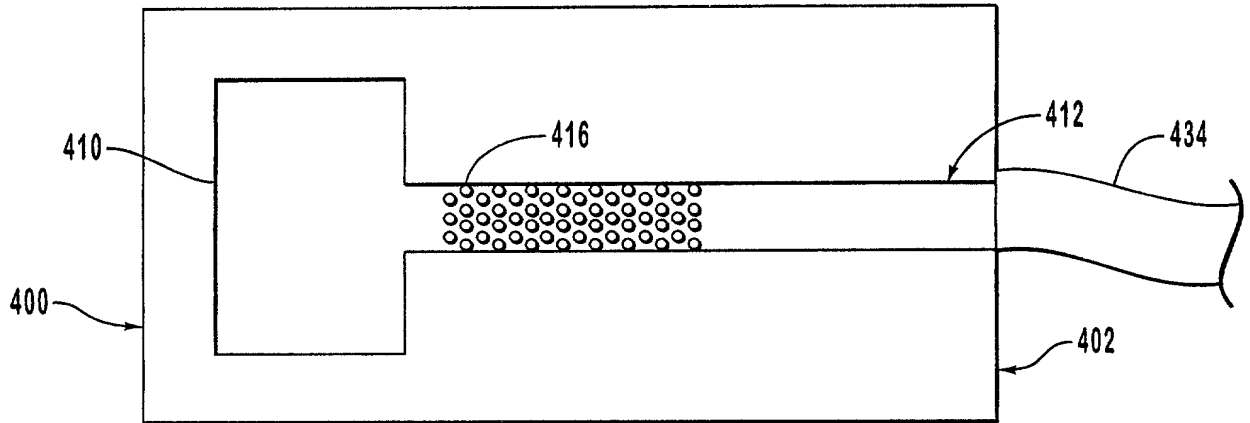


FIG. 26

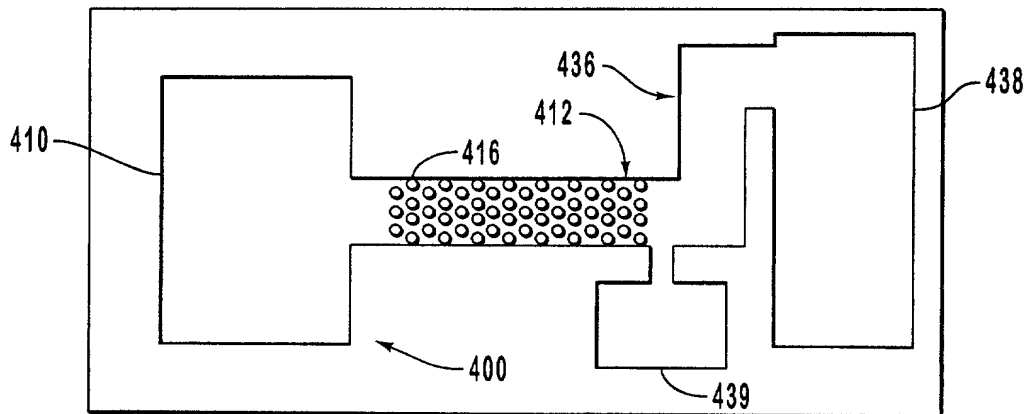
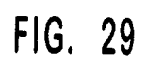
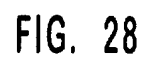


FIG. 27



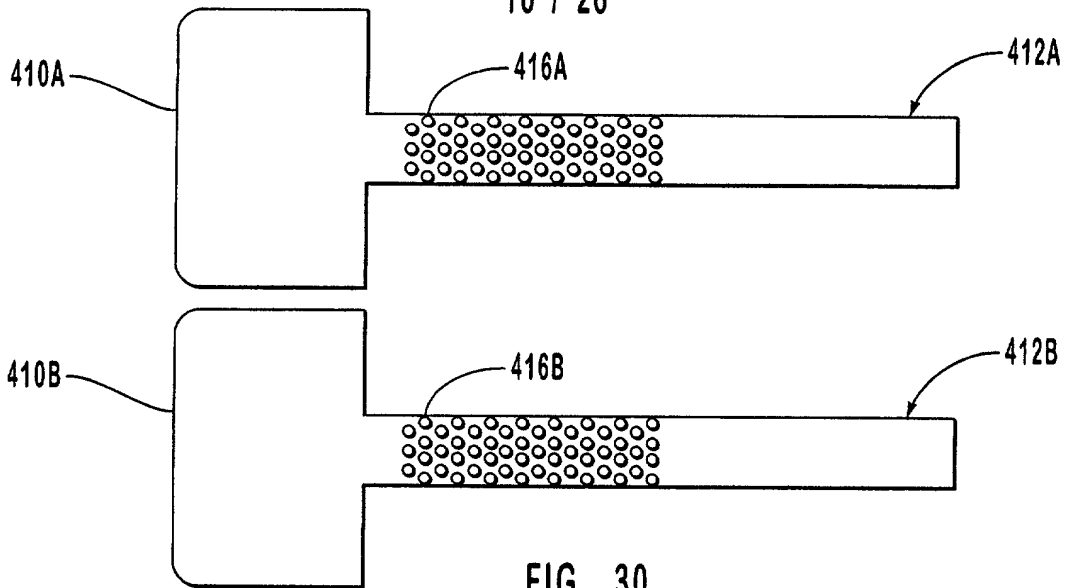


FIG. 30

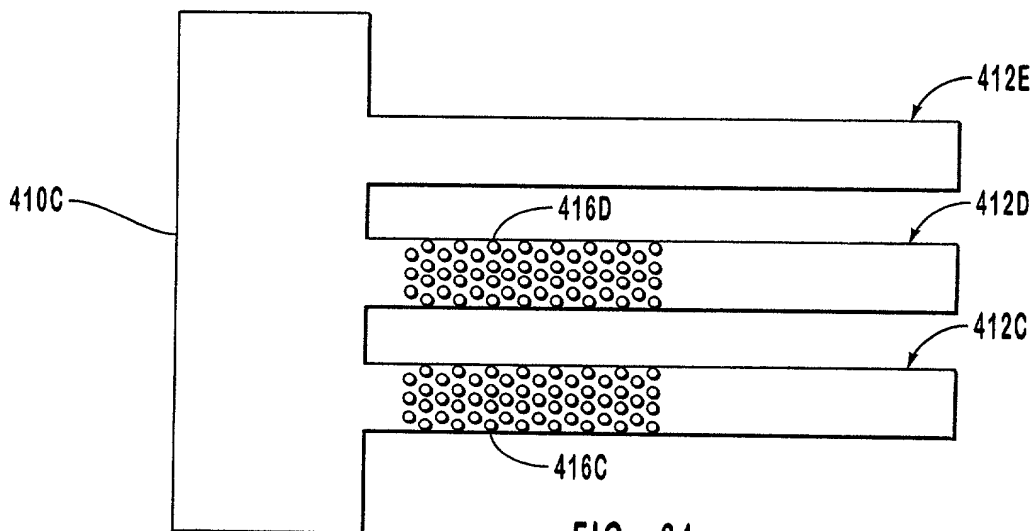
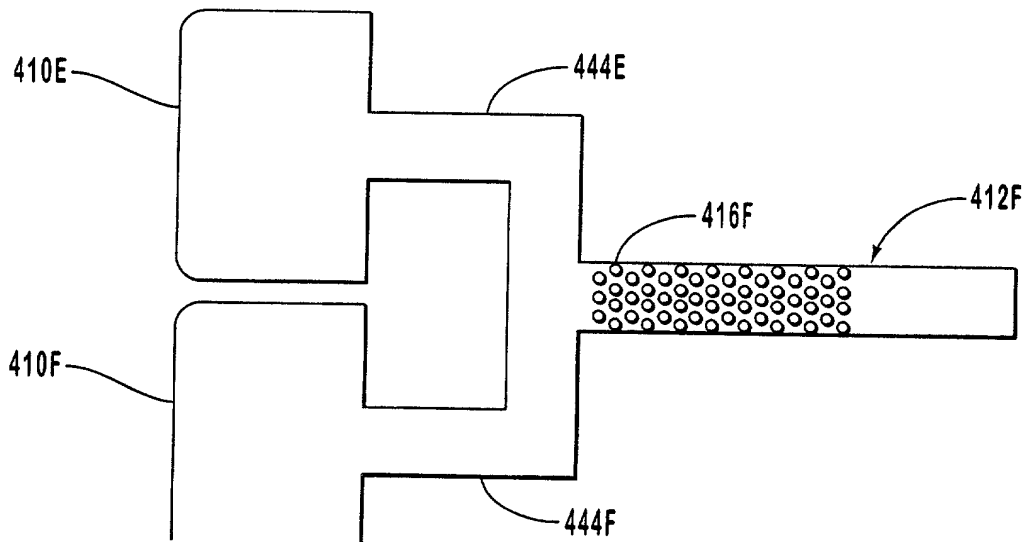


FIG. 31



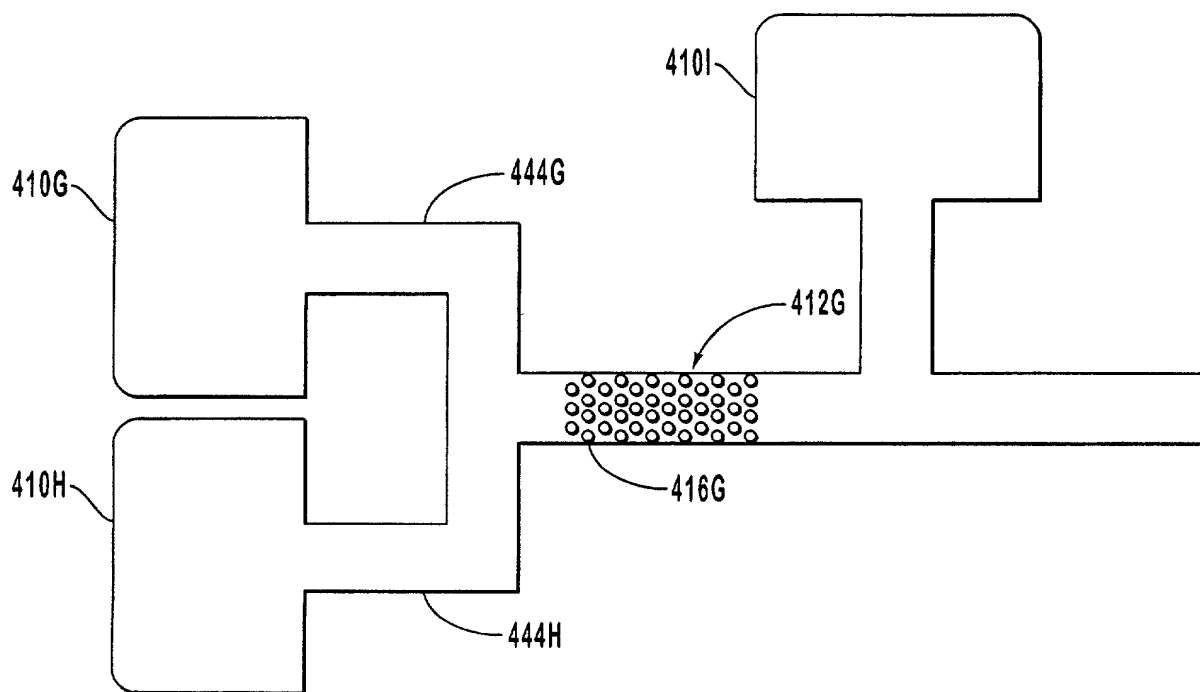


FIG. 33

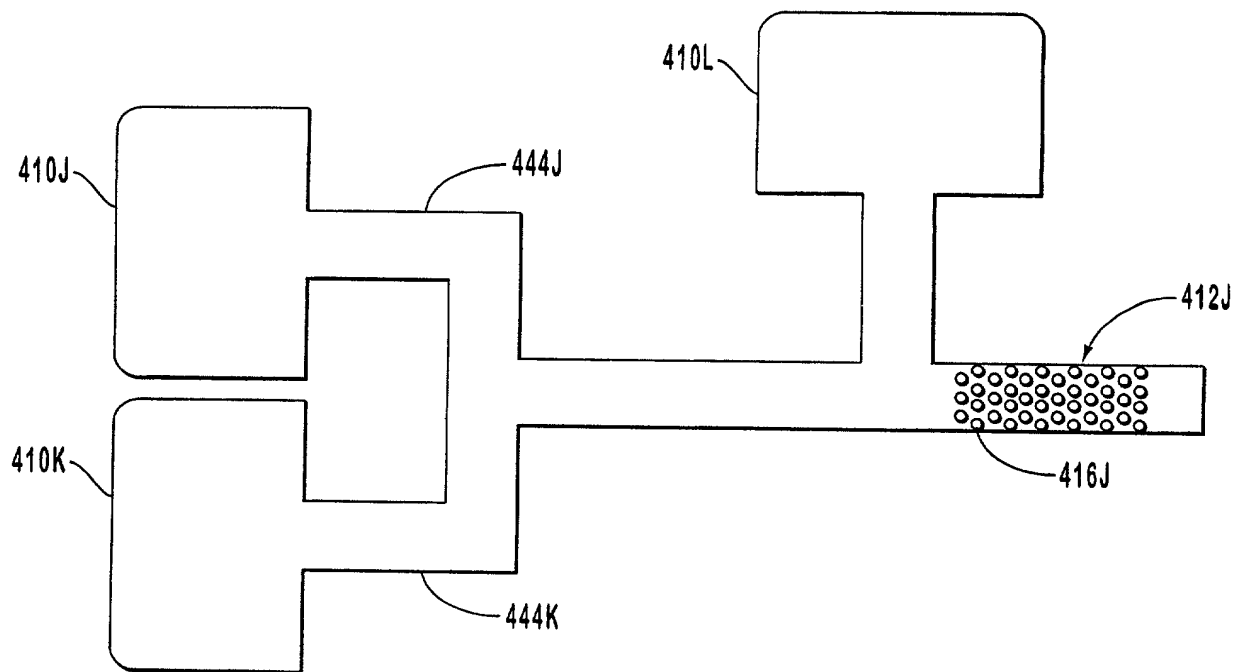


FIG. 34

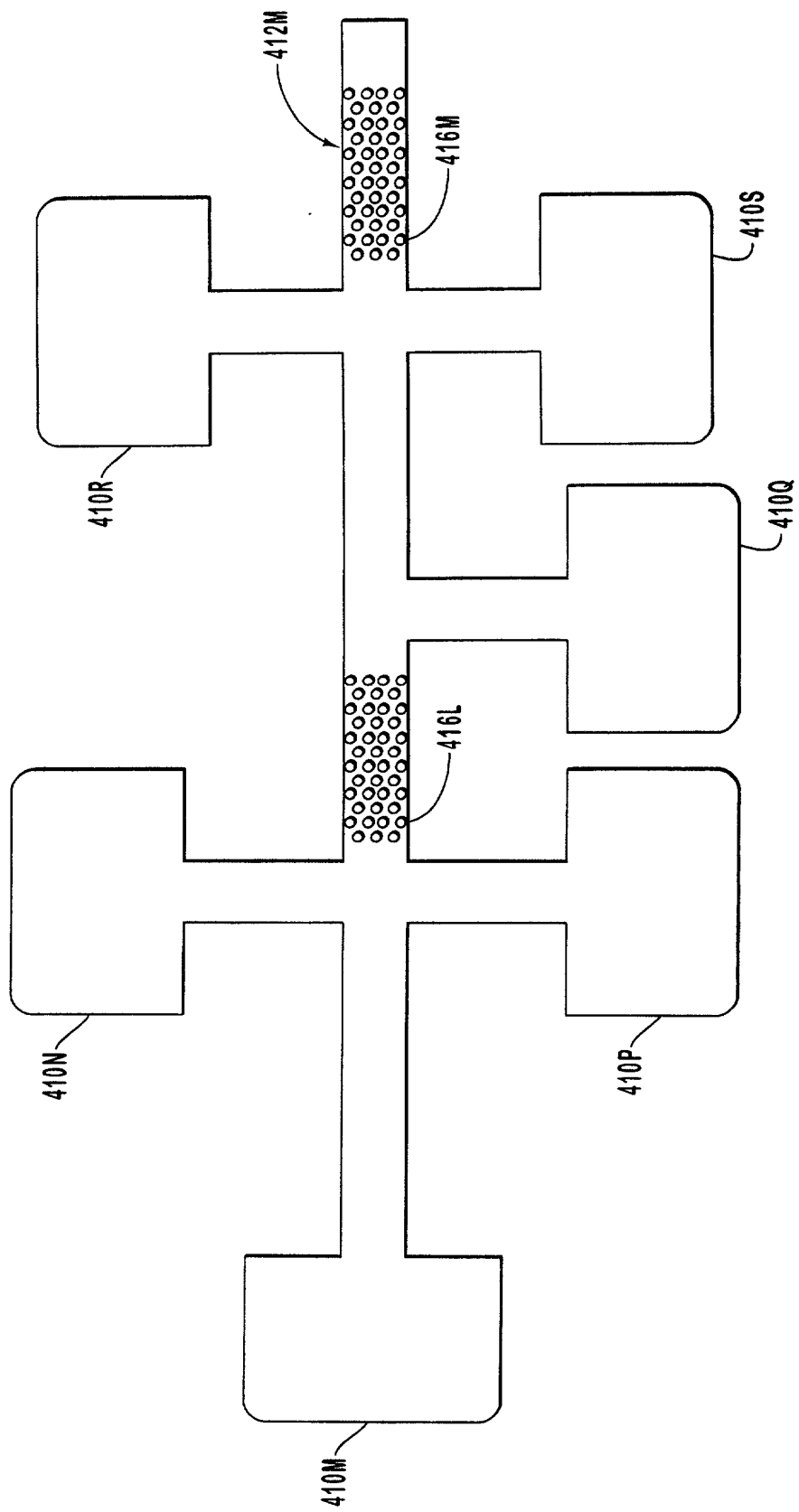


FIG. 35

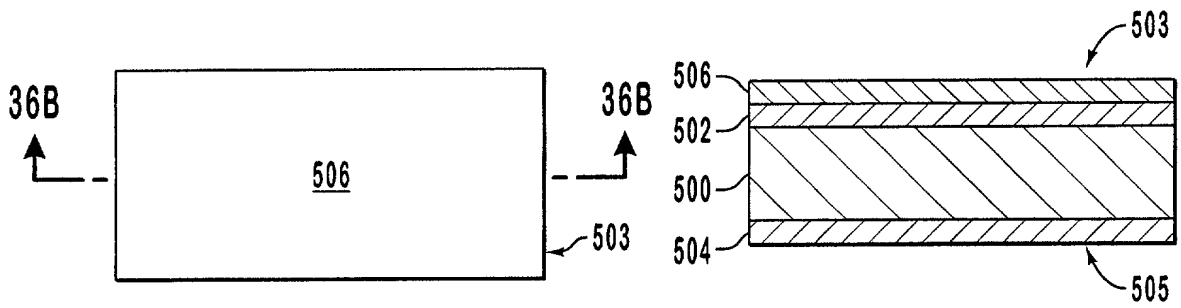


FIG. 36A

FIG. 36B

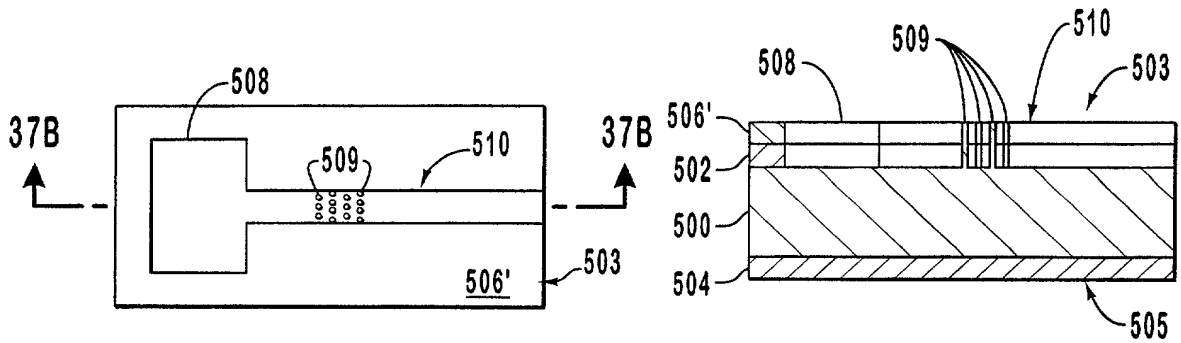


FIG. 37A

FIG. 37B

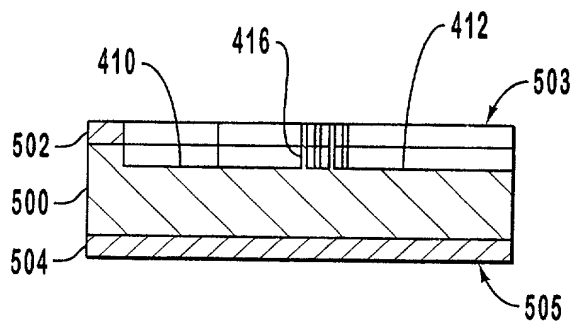


FIG. 38

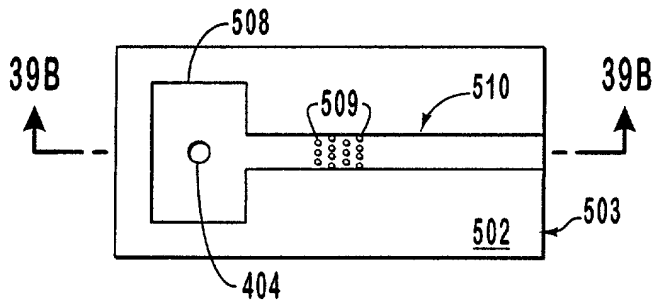


FIG. 39A

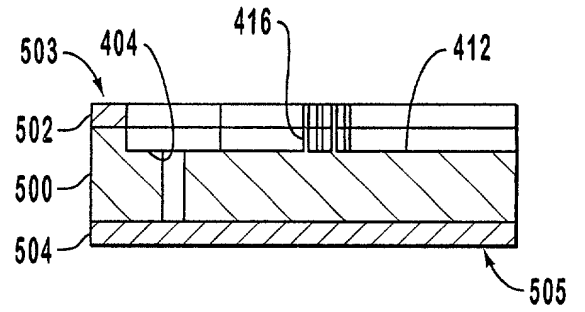


FIG. 39B

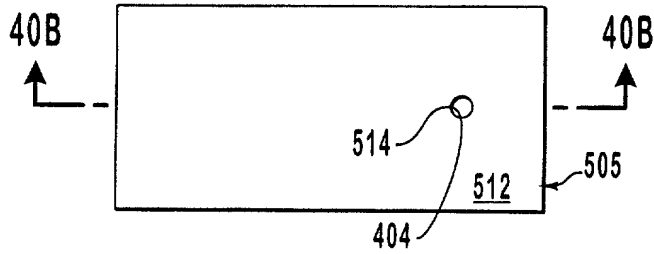


FIG. 40A

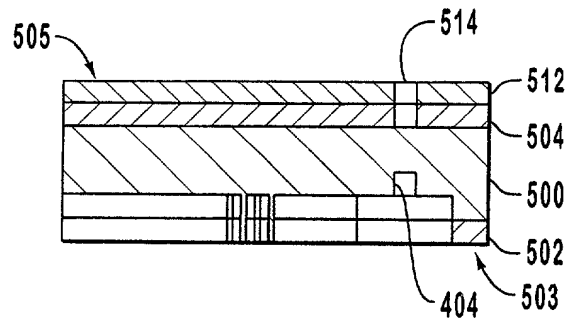


FIG. 40B

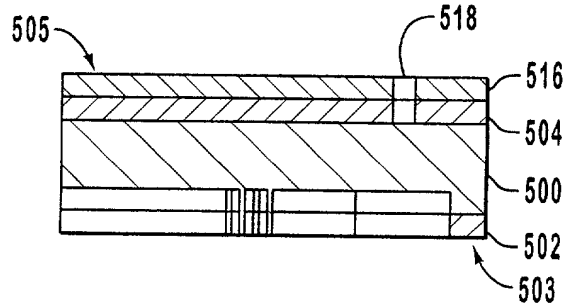


FIG. 41

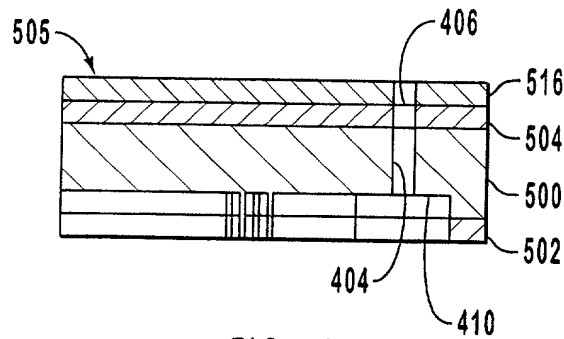


FIG. 42

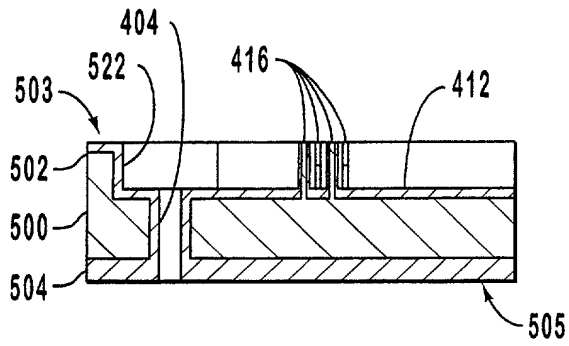


FIG. 43

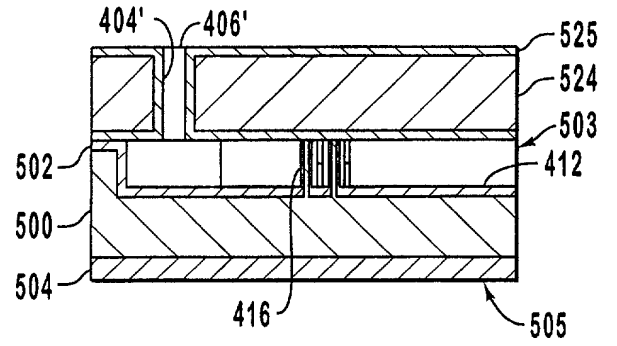


FIG. 45

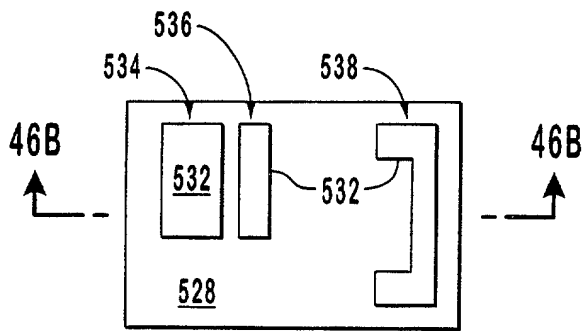


FIG. 46A

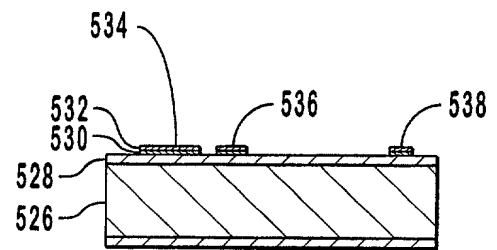


FIG. 46B

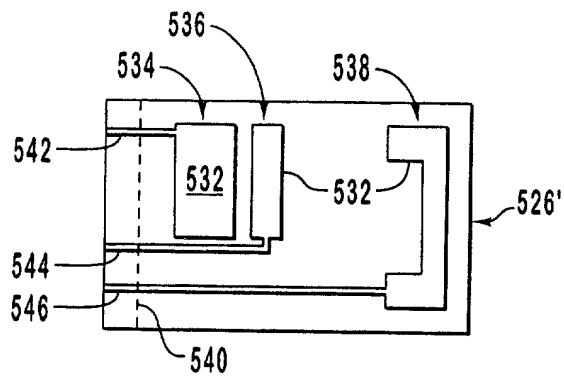


FIG. 46C

FIG. 44A

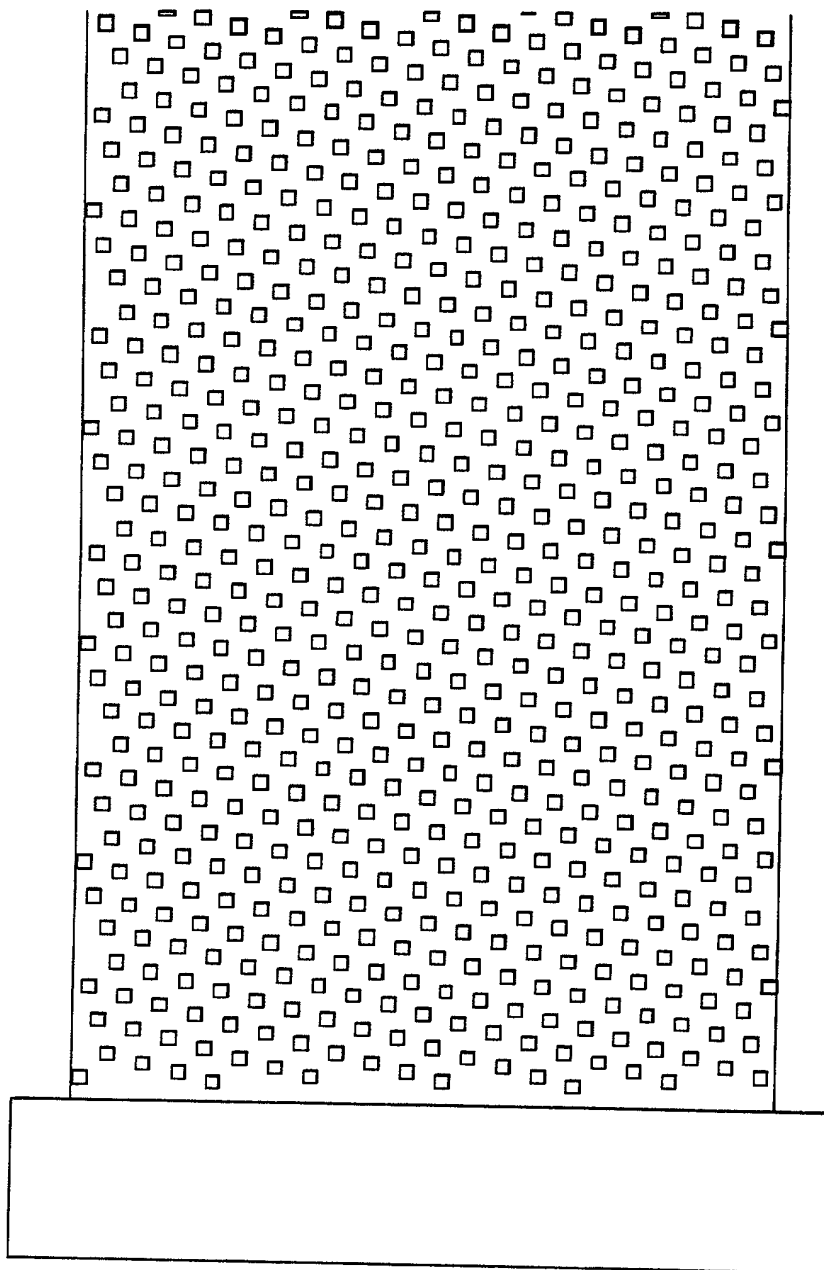


FIG. 44A

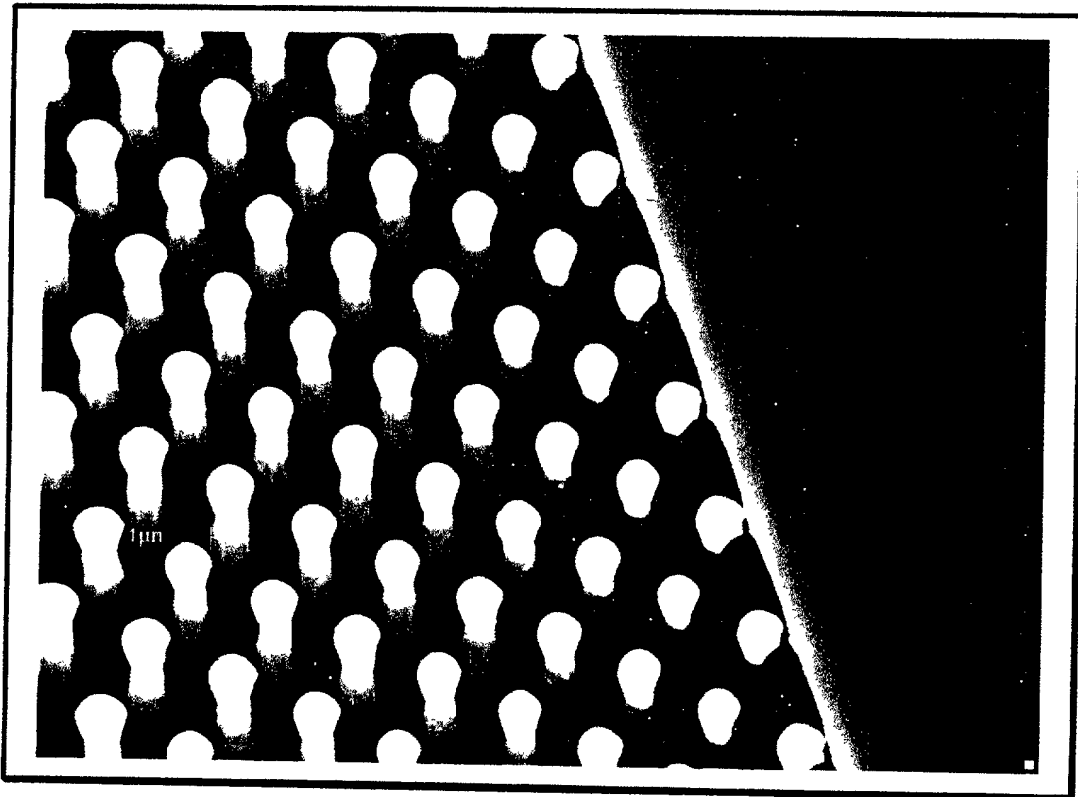


FIG. 44B

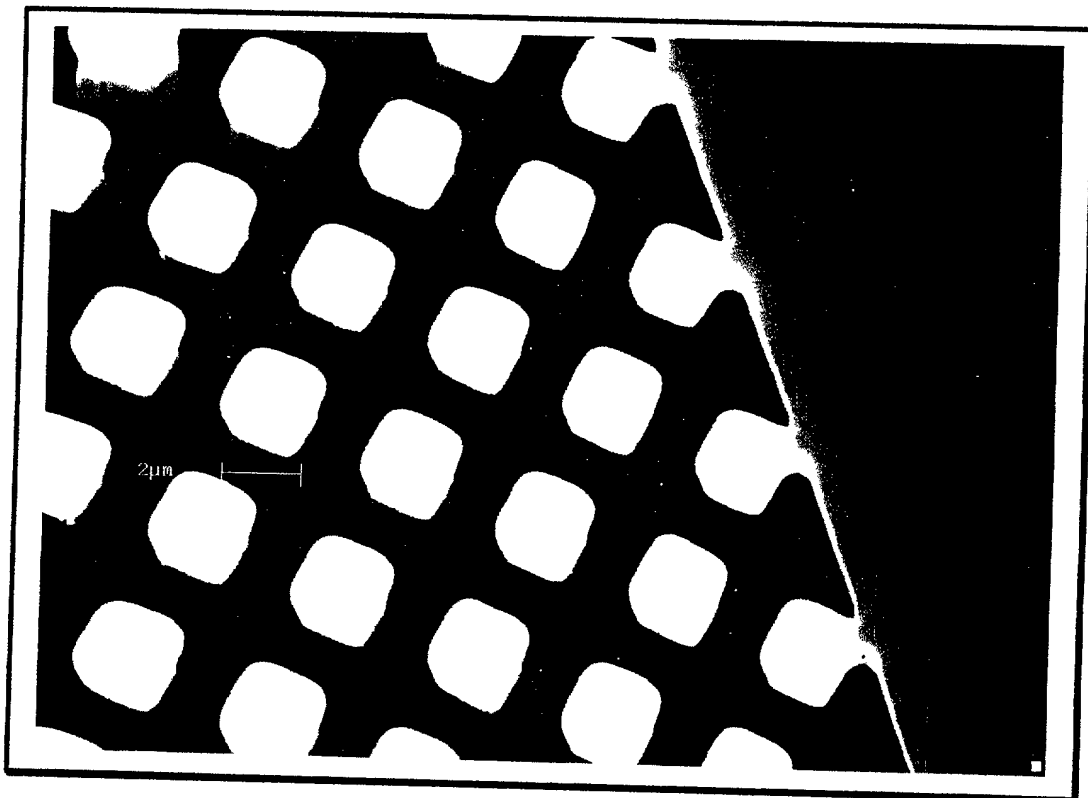


FIG. 44C

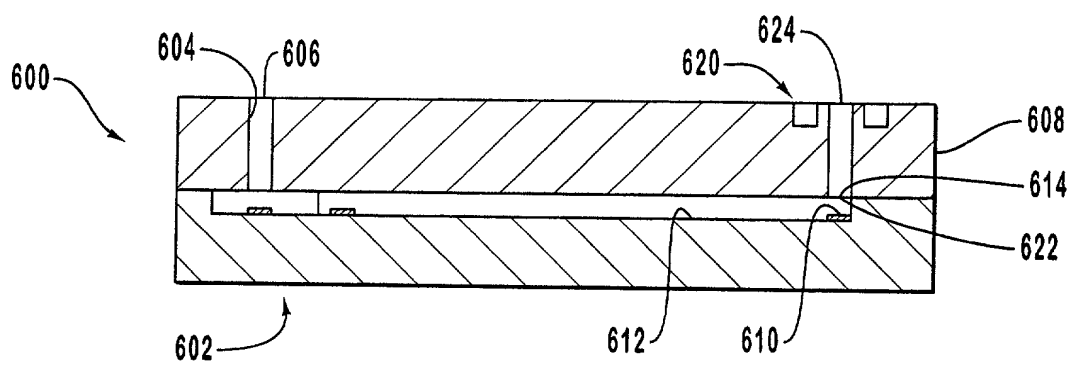


FIG. 47

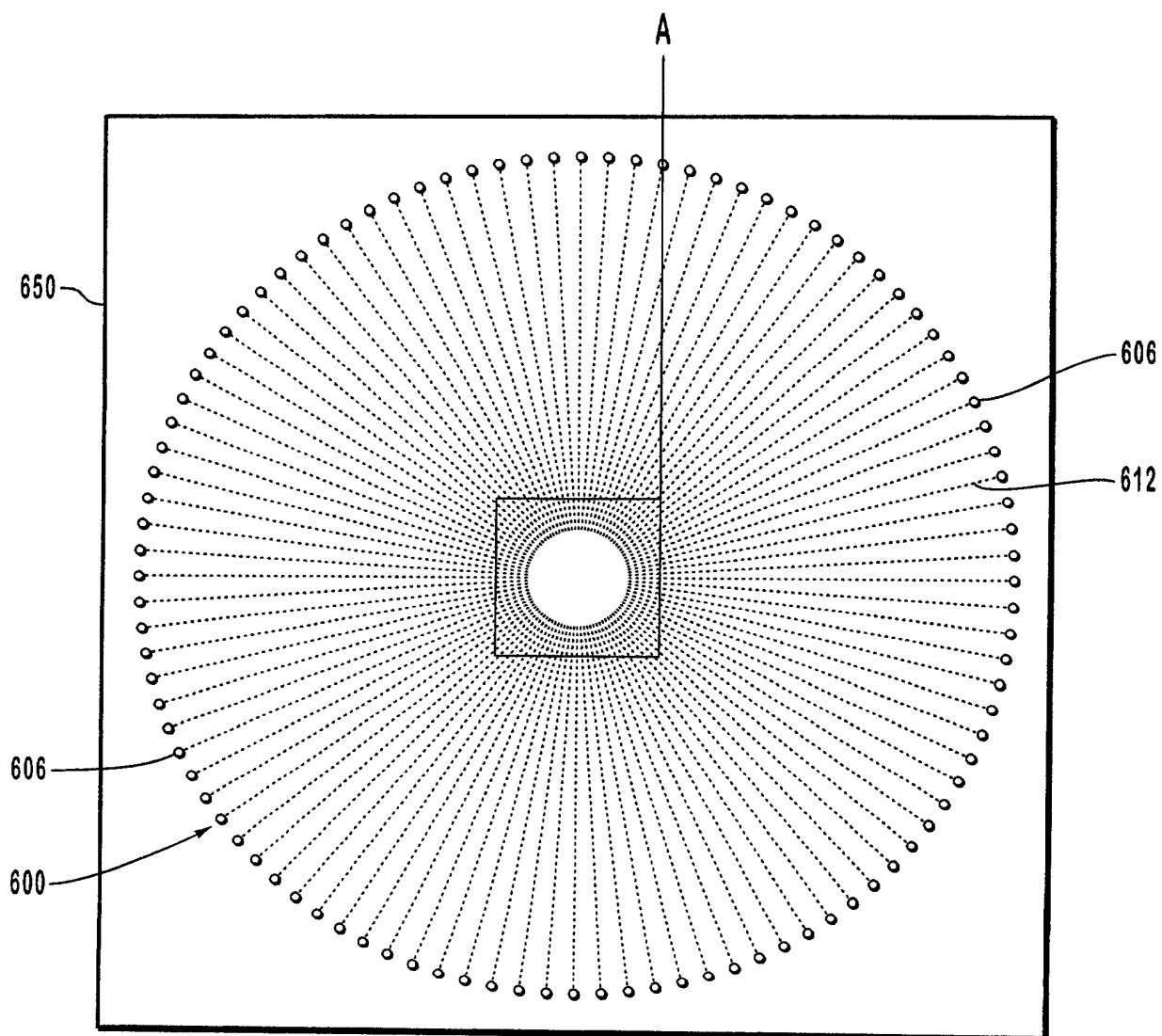


FIG. 48

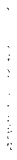


FIG. 49

Express Mail Label No. EL675131575US

PATENT APPLICATION

Docket: 14917.1.4

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Moon et al.

Prior Application

Serial No.: 09/156,507

For:

INTEGRATED MONOLITHIC MICROFABRICATED
ELECTROSPRAY AND LIQUID
CHROMATOGRAPHY SYSTEM AND METHOD

)
)
)
)
) Art Unit
) 1741
)
)
)

ASSOCIATE POWER OF ATTORNEY

Assistant Commissioner for Patents
Washington, D. C. 20231

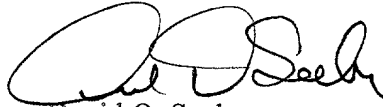
Sir:

Please recognize KYLE H. FLINDT, Registration No. 42,539, and WILLIAM J. ATHAY, Registration No. 44,515 as associate attorneys for us in the above-entitled application. Please address all future written and telephonic communications to:

David O. Seeley
WORKMAN, NYDEGGER & SEELEY
1000 Eagle Gate Tower
60 East South Temple
Salt Lake City, Utah 84111

Dated this 31st day of October 2000.

Respectfully submitted,



David O. Seeley
Attorney for Applicants
Registration No. 30,148

WORKMAN, NYDEGGER & SEELEY
1000 Eagle Gate Tower
60 East South Temple
Salt Lake City, Utah 84111
Telephone: (801) 533-9800
Fascimile: (801) 328-1707

G:\DATA\WPDOCS3\CM\1491714.APA

COMBINED DECLARATION FOR PATENT
APPLICATION AND POWER OF ATTORNEY
(Includes Reference to PCT International Applications)

ATTORNEY'S DOCKET NUMBER
200701/1030

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**INTEGRATED MONOLITHIC MICROFABRICATED ELECTROSPRAY AND LIQUID
CHROMATOGRAPHY SYSTEM AND METHOD**

the specification of which (check only one item below):

- ☐ is attached hereto.
- ☒ was filed as U.S. Patent Application Serial No. 09/156,507 on September 17, 1998 and was amended on _____ (if applicable).
- ☐ was filed as PCT International Application No. _____ on _____ and was amended under PCT Article 19 on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specifications, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (IF PCT, indicate "PCT")	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT International filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS		STATUS (Check One)			
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED	
PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (if any)			

ATTORNEY'S DOCKET NUMBER
200701/1030

Send Correspondence to: **Michael L. Goldman**
Nixon, Hargrave, Devans & Doyle LLP
Clinton Square, P.O. Box 1051
Rochester, New York 14603

201	FULL NAME OF INVENTOR	FAMILY NAME Moon	FIRST GIVEN NAME James	SECOND GIVEN NAME E.
	RESIDENCE & CITIZENSHIP	CITY Ithaca	STATE/FOREIGN COUNTRY New York	COUNTRY OF CITIZENSHIP United States
	POST OFFICE ADDRESS	P.O. ADDRESS 122 E. Remington Road	CITY Ithaca	STATE & ZIP CODE/CTRY New York 14850/U.S.A./
202	FULL NAME OF INVENTOR	FAMILY NAME Davis	FIRST GIVEN NAME Timothy	SECOND GIVEN NAME J.
	RESIDENCE & CITIZENSHIP	CITY Trumansburg	STATE/FOREIGN COUNTRY New York	COUNTRY OF CITIZENSHIP United States
	POST OFFICE ADDRESS	P.O. ADDRESS 2283 State Route 96	CITY Trumansburg	STATE & ZIP CODE/CTRY New York 14886/U.S.A.
203	FULL NAME OF INVENTOR	FAMILY NAME Galvin	FIRST GIVEN NAME Gregory	SECOND GIVEN NAME J.
	RESIDENCE & CITIZENSHIP	CITY Ithaca	STATE/FOREIGN COUNTRY New York	COUNTRY OF CITIZENSHIP United States
	POST OFFICE ADDRESS	P.O. ADDRESS 124 E. King Road	CITY Ithaca	STATE & ZIP CODE/CTRY New York 14850/U.S.A.
204	FULL NAME OF INVENTOR	FAMILY NAME Schultz	FIRST GIVEN NAME Gary	SECOND GIVEN NAME A.
	RESIDENCE & CITIZENSHIP	CITY Ithaca	STATE/FOREIGN COUNTRY New York	COUNTRY OF CITIZENSHIP United States
	POST OFFICE ADDRESS	P.O. ADDRESS 323 Richard Place	CITY Ithaca	STATE & ZIP CODE/CTRY New York 14850/U.S.A.
205	FULL NAME OF INVENTOR	FAMILY NAME Corso	FIRST GIVEN NAME Thomas	SECOND GIVEN NAME N.
	RESIDENCE & CITIZENSHIP	CITY Freeville	STATE/FOREIGN COUNTRY New York	COUNTRY OF CITIZENSHIP United States
	POST OFFICE ADDRESS	P.O. ADDRESS 5 Mineah Road, Apt. 7	CITY Freeville	STATE & ZIP CODE/CTRY New York 13068/U.S.A.
206	FULL NAME OF INVENTOR	FAMILY NAME Lowes	FIRST GIVEN NAME Stephen	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY Freeville	STATE/FOREIGN COUNTRY New York	COUNTRY OF CITIZENSHIP United States
	POST OFFICE ADDRESS	P.O. ADDRESS 418 Ferguson Road	CITY Freeville	STATE & ZIP CODE/CTRY New York 13068/U.S.A.

Page 2 of 2

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statement may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201

SIGNATURE OF INVENTOR 202

SIGNATURE OF INVENTOR 203

DATE _____

DATE _____

DATE _____

SIGNATURE OF INVENTOR 204

SIGNATURE OF INVENTOR 205

SIGNATURE OF INVENTOR 206

DATE 12 MAR 96

DATE 12 MAR 99

DATE 12 MAR 99

DATE 12 MAR 96

DATE 12 MAR 99

DATE 12 MAR 99

Figure 1 consists of three vertically stacked panels. The top panel is a plot of the relic density $\Omega_{\text{DM}} h^2$ versus the mass $m_{\tilde{\chi}_1^0}$ (GeV). It shows several curves for different values of $m_{\tilde{g}}$ (1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0). The middle panel shows the relic density $\Omega_{\text{DM}} h^2$ versus $m_{\tilde{\chi}_1^0}$ (GeV) for different values of $m_{\tilde{g}}$ (1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0). The bottom panel shows the relic density $\Omega_{\text{DM}} h^2$ versus $m_{\tilde{\chi}_1^0}$ (GeV) for different values of $m_{\tilde{g}}$ (1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0).

COMBINED DECLARATION FOR PATENT
APPLICATION AND POWER OF ATTORNEY
(Includes Reference to PCT International Applications)

ATTORNEY'S DOCKET NUMBER
200701/1030

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**INTEGRATED MONOLITHIC MICROFABRICATED ELECTROSPRAY AND LIQUID
CHROMATOGRAPHY SYSTEM AND METHOD**

the specification of which (check only one item below):

- ☐ is attached hereto.
- ☒ was filed as U.S. Patent Application Serial No. 09/156,507 on September 17, 1998 and was amended on _____ (if applicable).
- ☐ was filed as PCT International Application No. _____ on _____ and was amended under PCT Article 19 on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specifications, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY (IF PCT, indicate "PCT")	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT International filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS		STATUS (Check One)			
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED	
PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (if any)			

**COMBINED DECLARATION FOR PATENT APPLICATION
AND POWER OF ATTORNEY (Continue)**

ATTORNEY'S DOCKET NUMBER
200701/1030

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. **Michael L. Goldman, Registration No. 30,727, Gunnar G. Leinberg, Registration No. 35,584; Dennis M. Connolly, Registration No. 40,964; Edwin V. Merkel, Registration No. 40,087, Jeffery B. Arnold, Registration No. 39,540**

Send Correspondence to: **Michael L. Goldman**
Nixon, Hargrave, Devans & Doyle LLP
Clinton Square, P.O. Box 1051
Rochester, New York 14603

Direct Telephone Calls to:
(name and telephone number)
Michael L. Goldman
(716) 263-1304

201	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/CTRY
		Moon	James	E.
		Ithaca	New York	United States
		122 E. Remington Road	Ithaca	New York 14850/U.S.A./
202	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/CTRY
		Davis	Timothy	J.
		Trumansburg	New York	United States
		2283 State Route 96	Trumansburg	New York 14886/U.S.A.
203	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/CTRY
		Galvin	Gregory	J.
		Ithaca	New York	United States
		124 E. King Road	Ithaca	New York 14850/U.S.A.
204	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/CTRY
		Schultz	Gary	A.
		Ithaca	New York	United States
		303 Richard Place	Ithaca	New York 14850/U.S.A.
205	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/CTRY
		Corso	Thomas	N.
		Freeville	New York	United States
		5 Mineah Road, Apt. 7	Freeville	New York 13068/U.S.A.
206	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE/FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	P.O. ADDRESS	CITY	STATE & ZIP CODE/CTRY
		Lowes	Stephen	
		Ithaca	New York	United States
		700 Warren Road, Apt. 22/2D	Ithaca	New York 14850/U.S.A.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statement may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 201 <i>James E. Moon</i>	SIGNATURE OF INVENTOR 202 <i>Timothy J. ...</i>	SIGNATURE OF INVENTOR 203 <i>[Signature]</i>
DATE <i>March 11, 1999</i>	DATE <i>March 11, 1999</i>	DATE <i>3/11/99</i>
SIGNATURE OF INVENTOR 204	SIGNATURE OF INVENTOR 205	SIGNATURE OF INVENTOR 206
DATE	DATE	DATE

Page 3 of 3

007604" 5530450